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TITLE: CPP Giant Magnetoresistive Head
Having Antiferromagnetic Film
Disposed In Rear Of Element

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CPP GIANT MAGNETORESISTIVE HEAD HAVING ANTIFERROMAGNETIC FILM DISPOSED IN REAR of ELEMENT

BACKGROUND OF THE INVENTION

5   1.   Field of the Invention

The present invention relates to a CPP (Current Perpendicular to the Plane) giant magnetoresistive head in which a sensing current flows in the thickness direction (perpendicularly to the film plane).

10   2.   Description of the Related Art

Giant magnetoresistive (GMR) elements used for hard disk devices and magnetic sensors are roughly divided into a CIP (Current in the Plane) type in which a sensing current flows in parallel with the film plane of each of layers

15   constituting an element, and a CPP (Current Perpendicular to the Plane) type in which a sensing current flows perpendicularly to the film plane of each of the layers constituting an element.

Fig. 55 is a longitudinal sectional view showing the

20   structure of a CPP-GMR head using a conventional CPP-GMR element.   A CPP-GMR head 100 comprises a lower shield layer 110 extending in the X direction shown in the drawing, a lower nonmagnetic metal film 120 formed on the lower shield layer 110 at its center in the X direction, and a free

25   magnetic layer 131, a nonmagnetic metallic material layer 132, a pinned magnetic layer 133, an antiferromagnetic layer 134, and an upper nonmagnetic metal film 140, which are laminated on the lower nonmagnetic metal film 120.   The CPP-GMR head

100 further comprises an upper shield layer 150 formed over the upper nonmagnetic metal film 140 to extend in the X direction, hard bias layers 163 formed in contact with parts of the free magnetic layer 131 and both sides of the

5 nonmagnetic layer 132, insulating layers 161 filling in the respective spaces between the hard bias layers 163 and the lower shield layers 110, and insulating layers 164 filling in the respective spaces between the hard bias layers 163 and the upper shield layer 150. Furthermore, bias underlying

10 layers 162 are disposed between the hard bias layers 163 and the insulating layers 161.

In the CPP-GMR head having the above-described construction, a sensing current also flows through the antiferromagnetic layer 134 comprising, for example, Pt-Mn.

15 The antiferromagnetic layer 134 has a resistivity of about 200 $\mu\Omega \cdot$cm which is significantly higher than those of the nonmagnetic metal films 120 and 140, the free magnetic layer 131, and the pinned magnetic layer 133. Also, the antiferromagnetic layer 134 must be thickly formed for

20 maintaining antiferromagnetic characteristics. For example, when the distance between the upper and lower shields is about 600 Å, the thickness of the antiferromagnetic layer 134 is about 200 Å. When the thick antiferromagnetic layer 134 having high resistivity is provided, the antiferromagnetic

25 layer 134 has high resistance and thus generates heat when the sensing current flows therethrough. Since the temperature of the whole of the head is increased by the generated heat (Joule heat), the reliability and high-

frequency characteristics of the head deteriorate. Also, the thick antiferromagnetic layer 134 causes a difficulty in decreasing the shield distance between the upper and lower shield layers, thereby causing an disadvantage to increasing

5   the recording density.

Therefore, it has been recently proposed to omit the antiferromagnetic layer 134. However, in order to stabilize magnetization of the pinned magnetic layer 133 without using the antiferromagnetic layer 134, the material used for

10 forming the pinned magnetic layer 133 is greatly limited, and it is thus difficult to improve a change ($\Delta R \cdot A$) in magnetoresistance per unit area. Also, when the magnetization of the pinned magnetic layer 133 is stabilized without using the antiferromagnetic layer 134, the

15 magnetization of the pinned magnetic layer 133 is weakly pinned. Therefore, when the direction of a sensing current magnetic field generated by passing the sensing current is different from the direction of a magnetic moment of the pinned magnetic layer 133, the sensing current magnetic field

20 has the problem of fluctuating the magnetization direction of the pinned magnetic layer 133.

In a CIP-GMR head, only about 10 percent of a sensing current flows through an antiferromagnetic layer, and the sensing current never flows through shield layers, thereby

25 causing none of the above problems.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to

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provide a CPP giant magnetoresistive head capable of strongly

pinning magnetization of a pinned magnetic layer while

decreasing Joule heat, promoting a higher recording density

with narrowing of the distance between reproduction shields,

5   and increasing a change ($\Delta R \cdot A$) in magnetoresistance per unit

area and a sensing current to obtain high output.

The present invention has been achieved in consideration

of the following facts: an antiferromagnetic layer for

pinning magnetization of a pinned magnetic layer can be

10   provided outside of a sensing current path to avoid the heat

generation from the antiferromagnetic layer and decrease

Joule heat even when the sensing current flows, magnetization

of the pinned magnetic layer can be strongly pinned when the

area of contact between the pinned magnetic layer and the

15   antiferromagnetic layer is large, and a sensing current loss

can be further decreased by using an insulating

antiferromagnetic layer.

A CPP giant magnetoresistive head of the present

invention comprises lower and upper shield layers with a

20   predetermined shield distance therebetween, and a giant

magnetoresistive element comprising a pinned magnetic layer,

a free magnetic layer, and a nonmagnetic layer interposed

between the pinned magnetic layer and the free magnetic layer,

which are disposed between the upper and lower shield layers,

25   a current flowing perpendicularly to the film plane of the

giant magnetoresistive element, wherein an antiferromagnetic

layer is provided in the rear of the giant magnetoresistive

element in a height direction, for pinning the magnetization

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direction of the pinned magnetic layer in the height
direction.

The antiferromagnetic layer is preferably provided in
contact with the rear end surface of the pinned magnetic
5   layer in the height direction or the upper or lower surface
of a rear portion of the pinned magnetic layer in the height
direction.

The antiferromagnetic layer provided in contact with the
rear end surface of the pinned magnetic layer in the height
10   direction produces an exchange coupling magnetic field in the
interface with the rear end surface in the height direction,
and the magnetization direction of the pinned magnetic layer
is pinned by the exchange coupling magnetic field.

When the antiferromagnetic layer is provided in contact
15   with the upper or lower surface of the rear portion of the
pinned magnetic layer in the height direction, at least a
portion of the pinned magnetic layer extends to the rear of
the magnetoresistive element in the height direction.   In
this case, the antiferromagnetic layer produces an exchange
20   coupling magnetic field in the interface with the upper or
lower surface of the rear portion of the pinned magnetic
layer, which extends in the height direction, and the
magnetization direction of the pinned magnetic layer is
pinned by the exchange coupling magnetic field.   In this
25   configuration, the area of contact between the pinned
magnetic layer and the antiferromagnetic layer is larger than
that of the case in which the antiferromagnetic layer is
provided in contact with the rear end surface of the pinned

magnetic layer in the height direction, thereby pinning the magnetization direction of the pinned magnetic layer by a greater exchange coupling magnetic field.

The dimension of the pinned magnetic layer in the height direction is preferably larger than that in the track width direction. When the dimension of the pinned magnetic layer in the height direction is larger than that in the track width direction, shape anisotropy occurs in parallel with the height direction, and magnetization pinning of the pinned magnetic layer can also be strengthened by the shape anisotropy.

The pinned magnetic layer preferably comprises a magnetic material having a positive magnetostriction constant and is exposed at a surface facing a recording medium. In this case, the symmetry of two-dimensional isotropic stress applied to the pinned magnetic layer is broken to apply uniaxial tensile stress to the pinned magnetic layer in parallel with the height direction. This inverse magnetostrictive effect stabilizes the magnetization direction of the pinned magnetic layer in an uniaxial direction parallel to the height direction.

The pinned magnetic layer may be formed in a laminated ferrimagnetic structure comprising first and second pinned magnetic layers which are laminated with a nonmagnetic intermediate layer provided therebetween. In the giant magnetoresistive element, the nonmagnetic layer and the free magnetic layer may be formed above or below the second pinned magnetic layer.

As a contact form between the pinned magnetic layer and the antiferromagnetic layer, for example, first to sixth forms are given. In the first to third forms, the nonmagnetic layer and the free magnetic layer are formed on the second pinned magnetic layer, while in the fourth to sixth forms, the nonmagnetic layer and the free magnetic layer are formed below the second pinned magnetic layer.

In the first form in which the nonmagnetic layer and the free magnetic layer are formed on the second pinned magnetic layer, each of the first pinned magnetic layer, the nonmagnetic intermediate layer and the second pinned magnetic layer extends to the rear of the nonmagnetic layer and the free magnetic layer in the height direction, and the antiferromagnetic layer is formed on the rear portion of the second pinned magnetic layer which extends in the height direction. In this way, when the antiferromagnetic layer contacts the upper surface of the second pinned magnetic layer, a wide contact area (an area where an exchange coupling magnetic field occurs) can be secured between the second pinned magnetic layer and the antiferromagnetic layer to stably and strongly pin the magnetization of the pinned magnetic layer, as compared with the case in which the antiferromagnetic layer contacts the rear end of the second pinned magnetic layer in the height direction.

Also, nonmagnetic metal films are preferably interposed between the lower shield layer and the first pinned magnetic layer and between the free magnetic layer and the upper shield layer, for relieving the concentration of the sensing

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current in the lower shield layer and the upper shield layer. The nonmagnetic metal film may comprise a nonmagnetic metallic material containing at least one element of Au, Ag, Cu, Ru, Rh, Ir, Pd, Ni-Cr, (Ni-Fe)-Cr, and Cr. Particularly,

5   the nonmagnetic metal film interposed between the lower shield layer and the first pinned magnetic layer preferably comprises any one of Ta/Cu, Ta/Ru/Cu, Ta/Cr, Ta/Ni-Cr, Ta/(Ni-Fe)-Cr, and Cr, for causing the nonmagnetic metal layer to function as a seed layer including the first pinned

10   magnetic layer in the magnetoresistive element. The seed effect of the nonmagnetic metal film also stabilizes magnetization pinning of the first pinned magnetic layer. However, when the nonmagnetic metallic material used for forming the nonmagnetic metal film contains Cr, the Cr

15   content preferably exceeds 20 atomic percent.

Practically, an insulating layer is interposed between the antiferromagnetic layer and the upper shield layer. As a result, substantially no sensing current flows through the antiferromagnetic layer to decrease a shunt loss, thereby

20   improving reproduction output. Instead of interposing the insulating layer, an insulating antiferromagnetic layer may be used as the antiferromagnetic layer. Alternatively, an antiferromagnetic metal layer in contact with the upper surface of the second pinned magnetic layer and an insulating

25   antiferromagnetic layer laminated on the antiferromagnetic metal layer may be used as the antiferromagnetic layer. When the antiferromagnetic metal layer is interposed between the pinned magnetic layer and the insulating antiferromagnetic

layer, the pinned magnetic layer sufficiently couples with the insulating antiferromagnetic layer to produce a great exchange coupling magnetic field. The insulating antiferromagnetic layer comprises, for example, Ni-O or α-

5 Fe_2O_3, and the antiferromagnetic metal layer comprises, for example, Pt-Mn or Ir-Mn.

In the second form in which the nonmagnetic layer and the free magnetic layer are formed on the second pinned magnetic layer, each of the first pinned magnetic layer, the

10 nonmagnetic intermediate layer and the second pinned magnetic layer extends to the rear of the nonmagnetic layer and the free magnetic layer in the height direction, and the antiferromagnetic layer is formed in contact with the lower surface of the rear portion of the first pinned magnetic

15 layer which extends in the height direction. In this form, a wide contact area (an area where an exchange coupling magnetic field occurs) can be secured between the first pinned magnetic layer and the antiferromagnetic layer to stably and strongly pin the magnetization of the pinned

20 magnetic layer.

Also, a nonmagnetic metal film is preferably provided on the lower shield layer, for relieving the concentration of the sensing current. When the nonmagnetic metal film is provided, the antiferromagnetic layer is formed on the rear

25 end portion of the nonmagnetic metal film in the height direction, and the first pinned magnetic layer is practically formed over the antiferromagnetic layer and the nonmagnetic metal film. The nonmagnetic metal film provided on the lower

shield layer preferably comprises any one of Ta/Cu, Ta/Ru/Cu, Ta/Cr, Ta/Ni-Cr, Ta/(Ni-Fe)-Cr, and Cr, for causing the nonmagnetic metal layer to function as a seed layer including the first pinned magnetic layer in the magnetoresistive

5   element.   In order to relieve the concentration of the sensing current, a nonmagnetic metal film comprising a nonmagnetic metallic material containing at last one element of Au, Ag, Cu, Ru, Rh, Ir, Pd, Ni-Cr, (Ni-Fe)-Cr, and Cr may also be interposed between the upper shield layer and the

10   free magnetic layer.   However, when the nonmagnetic metallic material used for forming the nonmagnetic metal film contains Cr, the Cr content preferably exceeds 20 atomic percent.

An insulating layer is practically interposed between the upper shield layer and the rear portion of the second

15   pinned magnetic layer which extends in the height direction.

In order to eliminate a sensing current loss, the insulating antiferromagnetic layer is preferably used as the antiferromagnetic layer.   The insulating antiferromagnetic layer may comprise Ni-O or α-Fe$_2$O$_3$.

20   In the third form, a magnetostrictive enhancement layer is further provided immediately below the first pinned magnetic layer and interposed between the first pinned magnetic layer and the antiferromagnetic layer in a rear region in the height direction in the second form.   The

25   magnetostrictive enhancement layer preferably has the same composition as the antiferromagnetic layer and has a disordered crystal structure thinner than the antiferromagnetic layer, and produces mismatch strain in the

interface with the first pinned magnetic layer. When the crystal structures of the magnetostrictive enhancement layer and the first pinned magnetic layer are distorted in the interface therebetween, the magnetostriction of the first

5   pinned magnetic layer is increased to enhance magnetization pinning of the first pinned magnetic layer and the pinned magnetic layer due to the inverse magnetostrictive effect.

Each of the antiferromagnetic layer and the magnetostrictive enhancement layer preferably comprises a Z-

10 Mn alloy (wherein Z is at least one element of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe).

In order to distort the crystal structures of the magnetostrictive enhancement layer and the first pinned magnetic layer, the crystal of the first pinned magnetic

15 layer is preferably epitaxial or heteroepitaxial to the crystal of the magnetostrictive enhancement layer.

When the magnetostrictive enhancement layer comprises the Z-Mn alloy, the magnetostrictive enhancement layer has a face-centered cubic structure near at least the interface

20 with the first pinned magnetic layer, and an equivalent crystal plane represented by {111} plane is preferentially oriented in parallel with the interface.

The thickness of the magnetostrictive enhancement layer is preferably 5 Å to 50 Å. Within this thickness range, the

25 magnetostrictive enhancement layer comprising the Z-Mn alloy maintains the face-centered cubic structure (fcc) which is the crystal structure at the time of deposition. When the thickness of the magnetostrictive enhancement layer exceeds

50 Å, the crystal structure of the magnetostrictive enhancement layer is converted to a CuAuI ordered face-centered tetragonal structure (fct) exhibiting antiferromagnetic characteristics when heat of about 250°C is

5   applied.   However, even when the thickness of the magnetostrictive enhancement layer exceeds 50 Å, the magnetostrictive enhancement layer maintains the face-centered cubic structure (fcc), which is the crystal structure at the time of deposition, unless heat of about

10   250°C is applied.

The Z element content of the Z-Mn alloy used for forming the antiferromagnetic layer and the magnetostrictive enhancement layer is preferably 40 atomic percent to 95 atomic percent.   Within this range, the first pinned magnetic

15   layer takes a positive large value of magnetostriction constant, and thus magnetization of the first pinned magnetic layer is further stabilized.

The first pinned magnetic layer preferably has a face-centered cubic structure near at least the interface with the

20   magnetostrictive enhancement layer, and an equivalent crystal plane represented by {111} plane is preferentially oriented in parallel with the interface.   Since, as described above, the magnetostrictive enhancement layer has a face-centered cubic (fcc) structure, and an equivalent crystal plane

25   represented by {111} plane is preferentially oriented in parallel with the interface with the first pinned magnetic layer, the constituent atoms of the first pinned magnetic layer easily overlap the constituent atoms of the

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magnetostrictive enhancement layer. Namely, both layers are epitaxially jointed together. However, there is a predetermined difference or more between the nearest neighbor interatomic distance in {111} plane of the first pinned

5 magnetic layer and the nearest neighbor interatomic distance in {111} plane of the magnetostrictive enhancement layer. Therefore, the constituent atoms of the first pinned magnetic layer overlap the constituent atoms of the magnetostrictive enhancement layer while distorting the crystal structures of

10 both layers near the interface therebetween, thereby increasing the magnetostriction of the first pinned magnetic layer.

When the first pinned magnetic layer comprises Co or Co_nFe_m ($m \leq 20$ and $n + m = 100$), the first pinned magnetic

15 layer has a face-centered cubic structure, and an equivalent crystal plane represented by {111} plane is preferentially oriented in parallel with the interface.

The first pinned magnetic layer may have a body-centered cubic structure (bcc) near at least the interface with the

20 magnetostrictive enhancement layer, and an equivalent crystal plane represented by {110} plane is preferentially oriented in parallel with the interface. In this case, the constituent atoms of the first pinned magnetic layer easily overlap the constituent atoms of the magnetostrictive

25 enhancement layer, and both layers are heteroepitaxially jointed together. However, there is a predetermined difference or more between the nearest neighbor interatomic distance in {110} plane of the first pinned magnetic layer

and the nearest neighbor interatomic distance in {111} plane of the magnetostrictive enhancement layer. Therefore, the crystal structures of the first pinned magnetic layer and the magnetostrictive enhancement layer are distorted near the

5　interface therebetween, thereby increasing the magnetostriction of the first pinned magnetic layer.

When the first pinned magnetic layer comprises Co_nFe_m (m ≥ 20 and n + m = 100), the first pinned magnetic layer has a body-centered cubic structure (bcc), and an equivalent

10　crystal plane represented by {110} plane is preferentially oriented in parallel with the interface with the magnetostrictive enhancement layer. Co_nFe_m (m ≥ 20 and n + m = 100) having a body-centered cubic structure has a greater magnetostriction constant than that of Co or Co_nFe_m (m ≤ 20

15　and n + m = 100) having a face-centered cubic structure, particularly with a composition near m = 50, thereby exhibiting the greater inverse magnetostrictive effect. Co_nFe_m (m ≥ 20 and n + m = 100) having a body-centered cubic structure has high coercive force and can thus strengthen

20　magnetization pinning of the first pinned magnetic layer.

Furthermore, the first pinned magnetic layer may have a face-centered cubic structure near the interface with the magnetostrictive enhancement layer, an equivalent crystal plane represented by {111} plane being preferentially

25　oriented in parallel with the interface, and the first pinned magnetic layer may have a body-centered cubic structure near the interface with the nonmagnetic intermediate layer, an equivalent crystal plane represented by {110} plane being

preferentially oriented in parallel with the interface. In this way, when the first pinned magnetic layer has the body-centered cubic structure near the interface with the nonmagnetic intermediate layer, magnetostriction of the first

5   pinned magnetic layer is increased to exhibit the great inverse magnetostrictive effect. On the other hand, when the first pinned magnetic layer has the face-centered cubic structure near the interface with the magnetostrictive enhancement layer, the pinned magnetic layer, the nonmagnetic

10   intermediate layer and the free magnetic layer have constant crystal orientation, thereby increasing the change $\Delta R \cdot A$ in magnetoresistance per unit area.

When the first pinned magnetic layer has a composition of Co or Co_nFe_m ($m \leq 20$ and $n + m = 100$) near the interface

15   with the magnetostrictive enhancement layer, and a composition of Co_nFe_m ($m \geq 20$ and $n + m = 100$) near the interface with the nonmagnetic intermediate layer, the first pinned magnetic layer has a face-centered cubic structure in which an equivalent crystal plane represented by {111} plane

20   is preferentially oriented in parallel with the interface with the magnetostrictive enhancement layer near the interface, and has a body-centered cubic structure in which an equivalent crystal plane represented by {110} plane is preferentially oriented in parallel with the interface with

25   the nonmagnetic intermediate layer near the interface. Also, when the composition comprises Co_nFe_m ($m \geq 20$ and $n + m = 100$) near the interface with the nonmagnetic intermediate layer, a RKKY interaction between the first pinned magnetic

layer and the second pinned magnetic layer through the nonmagnetic intermediate layer is desirably strengthened. The first pinned magnetic layer has a Fe concentration gradually increasing from the interface with the

5   magnetostrictive enhancement layer to the interface with the nonmagnetic intermediate layer.

In the third form, nonmagnetic metal films may be interposed between the lower shield layer and the first pinned magnetic layer and between the free magnetic layer and

10   the upper shield layer. The nonmagnetic metal film preferably comprises a nonmagnetic metallic material containing at least one element of Au, Ag, Cu, Ru, Rh, Ir, Pd, Ni-Cr, (Ni-Fe)-Cr, and Cr. Particularly, the nonmagnetic metal film interposed between the lower shield layer and the

15   first pinned magnetic layer preferably comprises any one of Ta/Cu, Ta/Ru/Cu, Ta/Cr, Ta/Ni-Cr, Ta/(Ni-Fe)-Cr, and Cr, for causing the nonmagnetic metal layer to function as a seed layer including the first pinned magnetic layer in the magnetoresistive element. However, when the nonmagnetic

20   metallic material used for forming the nonmagnetic metal film contains Cr, the Cr content preferably exceeds 20 atomic percent.

Practically, an insulating layer is interposed between the upper shield layer and the second pinned magnetic layer

25   rearwardly extending in the height direction.

The antiferromagnetic layer is preferably an insulating antiferromagnetic layer, for eliminating a sensing current loss. The insulating antiferromagnetic layer may comprise

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Ni-O or α-Fe$_2$O$_3$.

In the fourth form, the nonmagnetic layer and the free magnetic layer are provided below provided the second pinned magnetic layer, and the first pinned magnetic layer extends

5   to the rear of the free magnetic layer, the nonmagnetic layer, the second pinned magnetic layer and the nonmagnetic intermediate layer in the height direction. Also, the antiferromagnetic layer is in contact with the upper surface of the rear portion of the first pinned magnetic layer

10   extending in the height direction. In this way, when the antiferromagnetic layer is in contact with the upper surface of the rear portion of the first pinned magnetic layer, a wide contact area (an area where an exchange coupling magnetic field occurs) can be secured between the first

15   pinned magnetic layer and the antiferromagnetic layer to stably and strongly pin the magnetization of the pinned magnetic layer.

Also, nonmagnetic metal films are preferably interposed between the lower shield layer and the free magnetic layer

20   and between the first pinned magnetic layer and the upper shield layer. The nonmagnetic metal film may comprise a nonmagnetic metallic material containing at least one element of Au, Ag, Cu, Ru, Rh, Ir, Pd, Ni-Cr, (Ni-Fe)-Cr, and Cr. Particularly, the nonmagnetic metal film interposed between

25   the lower shield layer and the free magnetic layer preferably comprises any one of Ta/Cu, Ta/Ru/Cu, Ta/Cr, Ta/Ni-Cr, Ta/(Ni-Fe)-Cr, and Cr, for causing the nonmagnetic metal layer to function as a seed layer for the magnetoresistive

element including the first pinned magnetic layer. However,
when the nonmagnetic metallic material used for forming the
nonmagnetic metal film contains Cr, the Cr content preferably
exceeds 20 atomic percent.

5   The nonmagnetic metal film interposed between the first
pinned magnetic layer and the upper shield layer may comprise
a first upper nonmagnetic metal film disposed to cover the
upper surface of the antiferromagnetic layer, and a second
upper nonmagnetic metal film disposed over the first upper
10   nonmagnetic metal film and the first pinned magnetic layer.
The first upper nonmagnetic metal film practically comprises
Cr for causing the first upper nonmagnetic metal film to
function as a stopper in the RIE (reactive ion etching) step
of forming the antiferromagnetic layer.

15   Practically, an insulating layer is disposed below the
first pinned magnetic layer and in the rear of the free
magnetic layer, the nonmagnetic layer, the second pinned
magnetic layer and the nonmagnetic intermediate layer in the
height direction.

20   The antiferromagnetic layer preferably comprises an
insulating antiferromagnetic layer or a laminate of an
antiferromagnetic metal layer in contact with the first
pinned magnetic layer and an insulating antiferromagnetic
layer laminated on the antiferromagnetic metal layer. When
25   the antiferromagnetic metal layer is interposed between the
pinned magnetic layer and the insulating antiferromagnetic
layer, a greater exchange coupling magnetic field can be
produced. The insulating antiferromagnetic layer comprises,

for example, Ni-O or α-Fe$_2$O$_3$, and the antiferromagnetic metal layer comprises, for example, Pt-Mn or Ir-Mn.

In the fifth form, the nonmagnetic layer and the free magnetic layer are formed below the second pinned magnetic layer, each of the second pinned magnetic layer, the nonmagnetic intermediate layer and the first pinned magnetic layer extends to the rear of the nonmagnetic layer and the free magnetic layer in the height direction, and the antiferromagnetic layer is formed in contact with the upper surface of the rear portion of the first pinned magnetic layer which extends in the height direction. In this way, when the antiferromagnetic layer is formed in contact with the upper surface of the rear portion of the first pinned magnetic layer, a wide contact area (an area where an exchange coupling magnetic field occurs) can be secured between the first pinned magnetic layer and the antiferromagnetic layer to stably and strongly pin the magnetization of the pinned magnetic layer. Also, not only the first pinned magnetic layer but also the whole of the pinned magnetic layer rearwardly extends in the height direction, and thus magnetic coupling between the first and second pinned magnetic layers due to a RKKY interaction can be strengthened.

Furthermore, an antioxidative layer comprising an inoxidizable nonmagnetic material may be provided between the nonmagnetic layer and the second pinned magnetic layer. The antioxidative layer is formed to a thickness of as small as 5 Å to 10 Å. The antioxidative layer with a thickness in this

range prevents surface oxidation of the nonmagnetic layer even when the nonmagnetic layer and the second pinned magnetic layer are discontinuously deposited by separate steps, thereby preventing deterioration of the giant

5   magnetoresistive effect of the giant magnetoresistive element.

In the fifth form, nonmagnetic metal films are preferably provided between the lower shield layer and the free magnetic layer and between the first pinned magnetic layer and the upper shield layer. As described above, the

10 nonmagnetic metal film may comprise a nonmagnetic metallic material containing at least one element of Au, Ag, Cu, Ru, Rh, Ir, Pd, Ni-Cr, (Ni-Fe)-Cr, and Cr. The nonmagnetic metal film interposed between the first pinned magnetic layer and the upper shield layer may comprise a first upper nonmagnetic

15 metal film disposed to cover the upper surface of the antiferromagnetic layer, and a second upper nonmagnetic metal film disposed over the first upper nonmagnetic metal film and the first pinned magnetic layer. In this case, the first upper nonmagnetic metal film preferably comprises Cr. The

20 nonmagnetic metal film interposed between the lower shield layer and the free magnetic layer preferably comprises any one of Ta/Cu, Ta/Ru/Cu, Ta/Cr, Ta/Ni-Cr, Ta/(Ni-Fe)-Cr, and Cr, for causing the nonmagnetic metal layer to function as a seed layer for the magnetoresistive element including the

25 first pinned magnetic layer. However, when the nonmagnetic metallic material used for forming the nonmagnetic metal film contains Cr, the Cr content preferably exceeds 20 atomic percent.

An insulating layer is practically interposed below the second pinned magnetic layer and in the rear of the free magnetic layer and the nonmagnetic layer in the height direction.

5   The antiferromagnetic layer preferably comprises an insulating antiferromagnetic layer or a laminate of an antiferromagnetic metal layer in contact with the first pinned magnetic layer and an insulating antiferromagnetic layer laminated on the antiferromagnetic metal layer. The

10   insulating antiferromagnetic layer comprises, for example, Ni-O or α-Fe_2O_3, and the antiferromagnetic metal layer comprises, for example, Pt-Mn or Ir-Mn.

In the sixth form, the nonmagnetic layer and the free magnetic layer are formed below the second pinned magnetic

15   layer, each of the first pinned magnetic layer, the nonmagnetic intermediate layer and the second pinned magnetic layer extends to the rear of the nonmagnetic layer and the free magnetic layer in the height direction, and the insulating antiferromagnetic layer is formed in contact with

20   the lower surface of the rear portion of the second pinned magnetic layer which extends in the height direction. In this way, when the insulating antiferromagnetic layer is formed in contact with the lower surface of the rear portion of the second pinned magnetic layer, a wide contact area (an

25   area where an exchange coupling magnetic field occurs) can be secured between the first pinned magnetic layer and the antiferromagnetic layer to stably and strongly pin the magnetization of the pinned magnetic layer. Also, not only

the first pinned magnetic layer but also the whole of the

pinned magnetic layer rearwardly extends in the height

direction, and thus magnetic coupling between the first and

second pinned magnetic layers due to a RKKY interaction can

5   be strengthened. The insulating antiferromagnetic layer may

comprise, for example, Ni-O or α-Fe$_2$O$_3$.

In each of the first to sixth forms, part or entirety of

the second pinned magnetic layer may comprise Fe-Co-Cu

(wherein Fe > 10 atomic percent, Co > 30 atomic percent, and

10   Cu > 5 atomic percent), Fe-Co-Cu-X (wherein X is at least one

element of Pt, Pd, Mn, Si, Au, and Ag), or Co$_2$MnY (wherein Y

is at least one element of Ge, Si, Sn, and Al). Similarly,

part or entirety of the free magnetic layer may comprise Fe-

Co-Cu (wherein Fe > 10 atomic percent, Co > 30 atomic percent,

15   and Cu > 5 atomic percent), Fe-Co-Cu-X (wherein X is at least

one element of Pt, Pd, Mn, Si, Au, and Ag), or Co$_2$MnY

(wherein Y is at least one element of Ge, Si, Sn, and Al).

The present invention can be applied to not only a CPP

giant magnetoresistive head comprising a single spin-valve

20   giant magnetoresistive element, but also a CPP giant

magnetoresistive head comprising a dual spin-valve giant

magnetoresistive element. The dual spin-valve type comprises

lower and upper shield layers with a predetermined shield

distance therebetween, and a dual spin-valve giant

25   magnetoresistive element comprising a lower pinned magnetic

layer, a lower nonmagnetic layer, a free magnetic layer, an

upper nonmagnetic layer and an upper pinned magnetic layer,

which are laminated in turn between the upper and lower

shield layers, a current flowing perpendicularly to the film plane of the giant magnetoresistive element. This CPP giant magnetoresistive head of the present invention is characterized in that an antiferromagnetic layer is provided in the rear of the giant magnetoresistive element in the height direction, for pinning the magnetization directions of the lower pinned magnetic layer and the upper pinned magnetic layer in the height direction.

Specifically, the lower pinned magnetic layer and the upper pinned magnetic layer preferably extend to the rear of the free magnetic layer, the lower nonmagnetic layer and the upper nonmagnetic layer in the height direction, and the antiferromagnetic layer produces an exchange coupling magnetic field in each of the interface with the upper surface of the rear portion of the lower pinned magnetic layer and the interface with the lower surface of the rear portion of the upper pinned magnetic layer, each of the rear portions extending in the height direction. Therefore, the magnetization directions of the lower pinned magnetic layer and the upper pinned magnetic layer are pinned by the respective exchange coupling magnetic fields. The antiferromagnetic layer preferably comprises an insulating antiferromagnetic layer or an antiferromagnetic layer comprising a laminate of an antiferromagnetic metal layer in contact with the lower pinned magnetic layer and an insulating antiferromagnetic layer in contact with the upper pinned magnetic layer. When the antiferromagnetic metal layer is interposed between the pinned magnetic layer and the

insulating antiferromagnetic layer, coupling between the pinned magnetic layer and the insulating antiferromagnetic layer is improved to further strengthen an exchange coupling magnetic field acting on the pinned magnetic layer. The

5 insulating antiferromagnetic layer comprises, for example, Ni-O or α-Fe_2O_3, and the antiferromagnetic metal layer comprises, for example, Pt-Mn or Ir-Mn.

In another form, each of a lower pinned magnetic layer and an upper pinned magnetic layer extends to the rear of a

10 free magnetic layer, a lower nonmagnetic layer and an upper nonmagnetic layer in the height direction. An antiferromagnetic layer preferably comprises a first antiferromagnetic layer for pinning the magnetization direction of the lower pinned magnetic layer in the height

15 direction by an exchange coupling magnetic field produced in the interface with the lower surface of the lower pinned magnetic layer, and a second antiferromagnetic layer for pinning the magnetization direction of the upper pinned magnetic layer in the height direction by an exchange

20 coupling magnetic field produced in the interface with the lower surface of the upper pinned magnetic layer. The first antiferromagnetic layer is preferably an antiferromagnetic metal layer comprising, for example, Pt-Mn or the like, and the second antiferromagnetic layer is preferably an

25 insulating antiferromagnetic layer comprising, for example, Ni-O or α-Fe_2O_3.

In the CPP giant magnetoresistive head of each of the forms, practically, the nonmagnetic layer is a Cu layer, and

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the magnetic intermediate layer is a Ru layer.

In the present invention, an antiferromagnetic layer is provided in the rear of a giant magnetoresistive element, for pinning the magnetization direction of a pinned magnetic

5 layer, and thus the antiferromagnetic layer is absent from the flowing path of a sensing current to prevent the heat generation from the antiferromagnetic layer even when the sensing current flows therethrough. Therefore, the Joule heat generated by passing the sensing current is

10 significantly decreased to suppress an increase in the element temperature and improve reliability. Also, an increase in recording density can be promoted with narrowing of the reproduction shield distance.

Furthermore, in the present invention, at least a

15 portion of the pinned magnetic layer extends to the rear of the giant magnetoresistive element in the height direction, and the antiferromagnetic layer provided in the rear of the giant magnetoresistive element in the height direction is in contact with the upper or lower surface of the extending rear

20 portion of the pinned magnetic layer. Therefore, a wide contact area (an area where an exchange coupling magnetic field occurs) can be secured between the pinned magnetic layer and the antiferromagnetic layer, thereby stably and strongly pinning magnetization of the pinned magnetic layer.

25 Furthermore, in the present invention, magnetization pinning of the pinned magnetic layer is strengthened by the inverse magnetostrictive effect, shape anisotropy and the seed effect, and thus magnetization of the pinned magnetic

layer is little fluctuated, thereby increasing a change ΔR·A
in magnetoresistance per unit area. Even if the direction of
a sensing current magnetic field is different from the
direction of magnetic moment (synthetic magnetic moment) of
5   the pinned magnetic layer, magnetization of the pinned
magnetic layer is not fluctuated by the sensing current
magnetic field, thereby increasing the sensing current
density and output.

Furthermore, in the present invention, an insulating
10 antiferromagnetic layer is provided for pinning the
magnetization direction of the pinned magnetic layer, and
thus the sensing current does not flow into the insulating
antiferromagnetic layer, thereby suppressing a current loss
and increasing output.
15

BRIEF DESCRIPTION OF THE DRAWINGS
Fig. 1 is a longitudinal sectional view showing the
structure of a CPP giant magnetoresistive head (CPP-GMR head)
according to a first embodiment of the present invention, as
20 viewed from a surface facing a recording medium;

Fig. 2 is a XY plan view showing a range in which the
upper large-area nonmagnetic metal film, the lower large-area
nonmagnetic metal film and the GMR element shown in Fig. 1
are formed;

25   Fig. 3 is a sectional view taken along line III-III in
Fig. 1;

Fig. 4 is a conceptual view showing a current path
produced by passing a sensing current from an upper shield

layer to a lower shield layer;

Fig. 5 is a longitudinal sectional view showing a step
of a method for manufacturing the CPP giant magnetoresistive
head shown in Fig. 1;

5   Fig. 6 is a partial sectional view showing the structure
of a CPP giant magnetoresistive head according to a second
embodiment of the present invention, taken along a central
line of an element;

Fig. 7 is a partial sectional view showing the structure
10   of the CPP giant magnetoresistive head shown in Fig. 6, as
viewed from a surface facing a recording medium;

Fig. 8 is a schematic top plan view showing the GMR
element shown in Fig. 6;

Figs. 9A and 9B are partial sectional views showing a
15   step of a method for manufacturing the CPP giant
magnetoresistive head shown in Figs. 6 to 8, in which Fig. 9A
is a partial section view from a surface facing a recording
medium, and Fig. 9B is a partial sectional view taken along a
central line of the element in parallel with the height
20   direction;

Figs. 10A and 10B are partial sectional views showing a
step after the step shown in Figs. 9, in which Fig. 10A is a
partial section view from the surface facing the recording
medium, and Fig. 10B is a partial sectional view taken along
25   a central line of the element in parallel with the height
direction;

Figs. 11A and 11B are partial sectional views showing a
step after the step shown in Figs. 10, in which Fig. 11A is a

partial section view from the surface facing the recording medium, and Fig. 11B is a partial sectional view taken along a central line of the element in parallel with the height direction;

5   Figs. 12A and 12B are partial sectional views showing a step after the step shown in Figs. 11, in which Fig. 12A is a partial section view from the surface facing the recording medium, and Fig. 12B is a partial sectional view taken along a central line of the element in parallel with the height

10   direction;

Fig. 13 is a schematic view illustrating the direction of a sensing current magnetic field and the direction of a synthetic magnetic moment of a pinned magnetic layer;

Fig. 14 is a partial sectional view showing the

15   structure of a CPP giant magnetoresistive head according to a third embodiment of the present invention, taken along a central line of an element;

Fig. 15 is a partial sectional view showing the structure of the CPP giant magnetoresistive head shown in Fig.

20   14, as viewed from a surface facing a recording medium;

Fig. 16 is a schematic top plan view showing the GMR element shown in Fig. 14;

Fig. 17 is a partial sectional view showing a step of a method for manufacturing the CPP giant magnetoresistive head

25   shown in Figs. 14 to 16, taken along a central line of an element in the height direction;

Fig. 18 is a partial sectional view showing a step after the step shown in Fig. 17, taken along a central line of the

element in the height direction;

Fig. 19 is a partial sectional view showing a step after the step shown in Fig. 18, taken along a central line of the element in the height direction;

5   Fig. 20 is a partial sectional view showing the structure of a CPP giant magnetoresistive head according to a fourth embodiment of the present invention, taken along a central line of an element;

Fig. 21 is a partial sectional view showing the

10   structure of the CPP giant magnetoresistive head shown in Fig. 20, as viewed from a surface facing a recording medium;

Fig. 22 is a schematic top plan view showing the GMR element shown in Fig. 20;

Fig. 23 is a schematic view illustrating a state in

15   which the crystal structures of a first pinned magnetic layer and a magnetostrictive enhancement layer are distorted while matching with each other;

Fig. 24 is a partial sectional view showing a step of a method for manufacturing the CPP giant magnetoresistive head

20   shown in Figs. 20 to 22, taken along a central line of the element in the height direction;

Fig. 25 is a partial sectional view showing a step after the step shown in Fig. 24, taken along a central line of the element in the height direction;

25   Fig. 26 is a partial sectional view showing the structure of a CPP giant magnetoresistive head according to a fifth embodiment of the present invention, taken along a central line of an element;

Fig. 27 is a partial sectional view showing the structure of the CPP giant magnetoresistive head shown in Fig. 26, as viewed from a surface facing a recording medium;

Fig. 28 is a schematic top plan view showing the GMR element shown in Fig. 26;

Fig. 29 is a partial sectional view showing the structure of a CPP giant magnetoresistive head according to a sixth embodiment of the present invention, taken along a central line of an element;

Fig. 30 is a partial sectional view showing the structure of the CPP giant magnetoresistive head shown in Fig. 29, as viewed from a surface facing a recording medium;

Fig. 31 is a schematic top plan view showing the GMR element shown in Fig. 29;

Fig. 32 is a partial sectional view showing a step of a method for manufacturing the CPP giant magnetoresistive head shown in Figs. 29 to 31, taken along a central line of the element in parallel with the height direction;

Fig. 33 is a partial sectional view showing a step after the step shown in Fig. 32, taken along a central line of the element in parallel with the height direction;

Fig. 34 is a partial sectional view showing a step after the step shown in Fig. 33, taken along a central line of the element in parallel with the height direction;

Fig. 35 is a partial sectional view showing a step after the step shown in Fig. 34, taken along a central line of the element in parallel with the height direction;

Fig. 36 is a partial sectional view showing the

structure of a CPP giant magnetoresistive head according to a

seventh embodiment of the present invention, taken along a

central line of an element;

Fig. 37 is a partial sectional view showing the

structure of the CPP giant magnetoresistive head shown in Fig.

36, as viewed from a surface facing a recording medium;

Fig. 38 is a schematic top plan view showing the GMR

element shown in Fig. 36;

Fig. 39 is a partial sectional view showing the

structure of a CPP giant magnetoresistive head according to

an eighth embodiment of the present invention, taken along a

central line of an element;

Fig. 40 is a partial sectional view showing the

structure of the CPP giant magnetoresistive head shown in Fig.

39, as viewed from a surface facing a recording medium;

Fig. 41 is a schematic top plan view showing the GMR

element shown in Fig. 39;

Fig. 42 is a partial sectional view showing the

structure of a CPP giant magnetoresistive head according to a

ninth embodiment of the present invention, taken along a

central line of an element;

Fig. 43 is a partial sectional view showing the

structure of a CPP giant magnetoresistive head according to a

tenth embodiment of the present invention, taken along a

central line of an element;

Fig. 44 is a partial sectional view showing the

structure of a CPP giant magnetoresistive head according to

an eleventh embodiment of the present invention, taken along

a central line of an element;

Fig. 45 is a partial sectional view showing the structure of the CPP giant magnetoresistive head shown in Fig. 44, as viewed from a surface facing a recording medium;

5   Fig. 46 is a schematic top plan view showing the GMR element shown in Fig. 44;

Fig. 47 is a partial sectional view showing a step of a method for manufacturing the CPP giant magnetoresistive head shown in Figs. 44 to 46, taken along a central line of the

10   element in parallel with the height direction;

Figs. 48A and 48B are partial sectional views showing a step after the step shown in Fig. 47, in which Fig. 48A is a partial section view from the surface facing the recording medium, and Fig. 48B is a partial sectional view taken along

15   a central line of the element in parallel with the height direction;

Fig. 49 is a partial sectional view showing the structure of a CPP giant magnetoresistive head according to a twelfth embodiment of the present invention, taken along a

20   central line of an element;

Fig. 50 is a partial sectional view showing the structure of the CPP giant magnetoresistive head shown in Fig. 49, as viewed from a surface facing a recording medium;

Fig. 51 is a schematic top plan view showing the GMR

25   element shown in Fig. 49;

Fig. 52 is a partial sectional view showing the structure of a CPP giant magnetoresistive head according to a thirteenth embodiment of the present invention, taken along a

central line of an element;

Fig. 53 is a partial sectional view showing the structure of the CPP giant magnetoresistive head shown in Fig. 52, as viewed from a surface facing a recording medium;

5   Fig. 54 is a schematic top plan view showing the GMR element shown in Fig. 52; and

Fig. 55 is a longitudinal sectional view showing the structure of a conventional CPP giant magnetoresistive head, as viewed from a surface facing a recording medium.

10

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described below with reference to the drawings. In each of the drawings, the X direction corresponds to the track width direction, the Y

15   direction corresponds to the direction of a leakage magnetic field from a recording medium, and the Z direction corresponds to the moving direction of the recording medium and the lamination direction of layers which constitute a giant magnetoresistive element.

20   Figs. 1 to 5 show a CPP giant magnetoresistive head (CPP-GMR head) according to a first embodiment of the present invention. Fig. 1 is a partial sectional view showing the structure of a CPP-GMR head 1, as viewed from a surface facing the recording medium, and Fig. 2 is a schematic top

25   plan view of a GMR element 30, and Fig. 3 is a partial sectional view showing the structure of the CPP-GMR head 1, taken along a central line of the element.

The CPP-GMR head 1 comprises lower and upper shield

layers 10 and 50 with a predetermined shield distance R-GL
therebetween in the Z direction shown in the drawing, a lower
large-area nonmagnetic metal film 20, the GMR element 30
exhibiting a giant magnetoresistive effect, and an upper
5   large-area nonmagnetic metal film 40, the lower and upper
large-area nonmagnetic metal films 20 and 40 and the GMR
element 30 being disposed between the lower and upper shield
layers 10 and 50.

        Each of the lower and upper shield layers 10 and 50
10   functions as a magnetic shield and an electrode, and is
formed in a sufficiently wider area than that of the GMR
element 30, as shown in Figs. 1 and 2.   Each of the lower and
upper shield layers 10 and 50 is formed to a thickness of
about 1 μm by using a soft magnetic material such as NiFe or
15   the like for obtaining a sufficient magnetic shield effect.

        The lower large-area nonmagnetic metal film 20 functions
as a gap layer formed directly on the lower shield layer 10,
and also functions as an electrode and a seed layer for
regularly forming the GMR element 30.   The upper large-area
20   nonmagnetic metal film 40 functions as a gap layer disposed
just below the upper shield layer 50, and also functions as
an electrode together with the upper shield layer 50.

        The lower large-area nonmagnetic metal film 20 and the
upper large-area nonmagnetic metal film 40 are in direct
25   contact with the lower surface (a free magnetic layer 31) and
the upper surface (a second pinned magnetic layer 33c),
respectively, of the GMR element 30.   As shown in Figs. 1 and
2, each of the lower and upper large-area nonmagnetic metal

films 20 and 40 has an area which is sufficiently larger than that of the GMR element 30 and substantially the same as that of the lower shield layer 10 and the upper shield layer 50.

Each of the lower and upper large-area nonmagnetic metal films 20 and 40 comprises a nonmagnetic metallic material having lower resistivity than that of the lower and upper shield layers 10 and 50. For example, each of the lower and upper large-area nonmagnetic metal films 20 and 40 preferably comprises at least one element of Au, Ag, Cu, Ru, Rh, Ir, Pd, Ni-Cr, (Ni-Fe)-Cr, and Cr. When the material contains Cr, the Cr content preferably exceeds 20 atomic percent. Each of the lower and upper large-area nonmagnetic metal films 20 and 40 may comprise a single film or a laminated film. In this embodiment, the lower large-area nonmagnetic metal film 20 comprises, for example, any one of Ta/Cu, Ta/Ru/Cu, Ta/Cr, Ta/Ni-Cr, Ta/(Ni-Fe)-Cr, and Cr, for causing the lower large-area nonmagnetic metal film 20 to function as a seed layer of the GMR element 30.

Each of the lower and upper large-area nonmagnetic metal films 20 and 40 is formed to a thickness of 1/4 or more of the shield distance R-GL. For example, when the shield distance R-GL is 480 Å to 800 Å, the thickness t20 or t40 of each of the lower and upper large-area nonmagnetic metal films 20 and 40 is preferably 60 Å to 300 Å. Within this thickness range, the resistivity of the large-area nonmagnetic metal films 20 and 40 can be decreased to about 1/5 to 1/10 of that of NiFe used as a material for forming the shield layers 10 and 50. Namely, the sheet resistance of

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the large-area nonmagnetic metal films 20 and 40 each having

a thickness of 60 Å to 300 Å corresponds to the sheet

resistance of a NiFe film having a thickness of 300 Å to 3000

Å.   Therefore, the sensing current easily flows through the

5   large-area nonmagnetic metal films 20 and 40 to relieve the

concentration of the sensing current in the interfaces

between the large-area nonmagnetic metal films 20 and 40 and

the shield layers 10 and 50.   Consequently, a resistance

change due to the AMR effect of the lower and upper shield

10   layers 10 and 50 can be suppressed to a low level.   The

thickness t20 of the lower large-area nonmagnetic metal film

20 may be the same as or different from that t40 of the upper

large-area nonmagnetic metal film 40.

    As shown in Fig. 1, the GMR element 30 is disposed at

15   the substantially center of the shield layers 10 and 50 and

the large-area nonmagnetic metal films 20 and 40 in the track

width direction (the X direction shown in the drawing), and

the GMR element 30 is sandwiched between the large-area

nonmagnetic metal films 20 and 40 in the thickness direction.

20   Since each of the large-area nonmagnetic metal films 20 and

40 is formed to a thickness of 1/4 or more of the shield

distance R-GL, the GMR element 30 is formed to a thickness of

3/4 or less of the shield distance R-GL.

    The GMR element 30 comprises the free magnetic layer 31,

25   a nonmagnetic layer 32 and a pinned magnetic layer 33 which

are laminated on the lower large-area nonmagnetic metal film

20 in that order from below.   As shown in Figs. 2 and 3, an

antiferromagnetic layer 34 is provided in the rear of the GMR

element 30 (strictly the free magnetic layer 31 and the

nonmagnetic layer 32) in the height direction (the Y

direction shown in the drawings), for pinning the

magnetization direction of the pinned magnetic layer 33.   The

5   free magnetic layer 31, the nonmagnetic layer 32 and the

pinned magnetic layer 33 have the same dimension (h1) in the

height direction.   The lower large-area nonmagnetic metal

film 20, the free magnetic layer 31, the nonmagnetic layer 32,

the pinned magnetic layer 33 and the upper large-area

10   nonmagnetic metal film 40 are exposed at the surface (ABS)

facing the recording medium, and the antiferromagnetic layer

34 is not exposed at the surface.   In the GMR element 30, the

pinned magnetic layer, the nonmagnetic layer and the free

magnetic layer may be laminated in that order from below,

15   which is opposite to the order in the embodiment shown in the

drawings.   Although not shown in the drawings of this

embodiment, a seed layer may be formed immediately below the

free magnetic layer 31, and a cap layer may be formed

immediately above the pinned magnetic layer 33.

20   The pinned magnetic layer 33 comprises layers each

comprising a magnetic material having a positive

magnetostriction constant, and is exposed at the surface

(ABS) facing the recording medium, as shown in Fig. 1.   When

the pinned magnetic layer 33 is exposed at the surface facing

25   the recording medium, the symmetry of two-dimensional

isotropic stress applied to the pinned magnetic layer 33 is

broken to apply uniaxial tensile stress to the pinned

magnetic layer 33 in parallel with the height direction.

This inverse magnetostrictive effect stabilizes the magnetization direction of the pinned magnetic layer 33 in a direction parallel to the height direction.

In this embodiment, the pinned magnetic layer 33 has a
5 laminated ferrimagnetic structure comprising a first pinned magnetic layer 33c and a second pinned magnetic layer 33a each comprising a magnetic material, and a nonmagnetic intermediate layer 33b disposed therebetween and comprising a nonmagnetic material.

10 The rear end of the first pinned magnetic layer 33c in the height direction (the Y direction) is in contact with the antiferromagnetic layer 34. The antiferromagnetic layer 34 contacts the rear end of the first pinned magnetic layer 33c in the height direction and produces an exchange coupling
15 magnetic field between the antiferromagnetic layer 34 and the rear end in the height direction. Consequently, the magnetization direction of the first pinned magnetic layer 33c is pinned in the height direction by the exchange coupling magnetic field. The first and second pinned
20 magnetic layers 33c and 33a have magnetizations antiparallel to each other due to a RKKY interaction therebetween through the nonmagnetic intermediate layer 33b. Namely, the magnetization direction of the second pinned magnetic layer 33a is antiparallel to the height direction.

25 Each of the first and second pinned magnetic layers 33c and 33a partially or entirely comprises Fe-Co-Cu (wherein Fe > 10 atomic percent, Co > 30 atomic percent, and Cu > 5 atomic percent), Fe-Co-Cu-X (wherein X is at least one

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element of Pt, Pd, Mn, Si, Au, and Ag), or Co_2MnY (wherein Y is at least one element of Ge, Si, Sn, and Al). The thickness of each of the first and second pinned magnetic layers 33c and 33a is, for example, about 10 Å to 70 Å. The

5 nonmagnetic intermediate layer 33b is formed to a thickness by using a material so as to produce the RKKY interaction between the first and second pinned magnetic layers 33c and 33a. In this embodiment, the nonmagnetic intermediate layer 33b is formed to a thickness of about 3 Å to 10 Å by using,

10 for example, Ru. The pinned magnetic layer 33 may have a single-layer structure or a laminated structure comprising a magnetic film instead of the laminated ferrimagnetic structure.

The antiferromagnetic layer 34 preferably comprises an

15 antiferromagnetic material containing Mn and element Z (element Z is at least one element of Pt, Pd, Ir, Rh, Ru, and Os), or an antiferromagnetic material containing Mn and elements Z and Z' (element Z' is at least one element of Ne, Ar, Kr, Xe, Be, B, C, N, Mg, Al, Si, P, Ti, V, Cr, Fe, Co, Ni,

20 Cu, Zn, Ga, Ge, Zr, Nb, Mo, Ag, Cd, Sn, Hf, Ta, W, Re, Au, Pb, and the rare earth elements). Such an antiferromagnetic material has excellent corrosion resistance and a high blocking temperature, and produces a great exchange coupling magnetic field at the interface between the antiferromagnetic

25 layer 34 and the first pinned magnetic layer 33c. The antiferromagnetic layer 34 is preferably formed to a thickness of 80 Å to 300 Å. In this embodiment, the thickness of the antiferromagnetic layer 34 is about 150 Å.

The nonmagnetic layer 32 preferably comprises a conductive material with low electric resistance, and in this embodiment, the nonmagnetic layer 32 comprises, for example, Cu. The nonmagnetic layer 32 is formed to a thickness of

5 about 25 Å, for example. The free magnetic layer 31 partially or entirely comprises Fe-Co-Cu (wherein Fe > 10 atomic percent, Co > 30 atomic percent, and Cu > 5 atomic percent), Fe-Co-Cu-X (wherein X is at least one element of Pt, Pd, Mn, Si, Au, and Ag), or Co_2MnY (wherein Y is at least one

10 element of Ge, Si, Sn, and Al). The thickness of the free magnetic layer 31 is, for example, about 100 Å. Although the free magnetic layer 31 has a single-layer structure comprising a magnetic film, a laminated structure or laminated ferrimagnetic structure comprising magnetic films

15 may be used. Furthermore, had bias layers 63 are in contact with both sides of the free magnetic layer 31 and the nonmagnetic layer 32, the hard bias layers 63 being magnetized in the track width direction. Also, a first or second insulating layer 61 or 64 with a thickness of several

20 Å to several tens Å may be interposed between the GMR element 30 and each hard bias layer 63. The magnetization of the free magnetic layer 31 is aligned in the track width direction (the X direction) by a longitudinal bias magnetic field of each of the hard bias layers 63.

25 The first insulating layers 61, bias underlying layers 62, the hard bias layers 63, and the second insulating layers 64 are laminated in that order from below on both sides of the GMR element 30 in the track width direction, and disposed

between the large-area nonmagnetic metal films 20 and 40.

The first and second insulating layers 61 and 64 comprise an insulating material, for example, Al_2O_3, SiO_2, or the like, and formed to fill in each of the spaces between

5 the hard bias layers 63 (and the hard bias underlying layers 62) and the large-area nonmagnetic metal films 20 and 40. Namely, the first insulating layers 61 are formed on the lower large-area nonmagnetic metal film 20 to have such a thickness that they contact parts of both sides of the free

10 magnetic layer 31. The second insulating layers 64 are formed on the respective hard bias layers 63 to have such a thickness that they contact both sides of the pinned magnetic layer 33.

The hard bias underlying layers 62 are provided for

15 improving the characteristics (coercive force Hc and remanence ratio S) of the hard bias layers 63 and increasing the bias magnetic fields produced from the hard bias layers 63. Each of the hard bias underlying layers 62 preferably comprises a metal film having a body-centered cubic structure

20 (bcc structure). Specifically, each of the hard bias underlying layers 62 preferably comprises at least one element of Cr, W, Mo, V, Mn, Nb, and Ta. Although the hard bias underlying layers 62 are preferably formed only below the respective hard bias layers 63, they may be slightly

25 interposed between both sides of the free magnetic layer 31 and the hard bias layers 63. The thickness of each of the hard bias underlying layers 62 formed between both sides of the free magnetic layer 31 and the hard bias layers 63 in the

track width direction is preferably 1 nm or less. When the hard bias underlying layers 62 are interposed between the hard bias layers 63 and the free magnetic layer 31, the hard bias layers 63 can be magnetically connected to the free

5 magnetic layer 31 to prevent a buckling phenomenon in which the ends of the free magnetic layer 31 are influenced by a demagnetizing field, thereby facilitating magnetic domain control of the free magnetic layer 31.

In the CPP-GMR head 1 having the above-described whole

10 structure, when the sensing current flows perpendicularly (in the thickness direction) to the film plane of the GMR element 30, a leakage magnetic field from the recording medium can be detected by using the giant magnetoresistive effect of the GMR element 30. In Fig. 4, an arrow shows a current path

15 produced by passing the sensing current from the upper shield layer 50 to the lower shield layer 10.

As shown in Fig. 4, the sensing current supplied to the upper shield layer 50 mostly flows into the upper large-area nonmagnetic metal film 40 having lower resistivity than that

20 of the upper shield layer 50. The sensing current flowing into the upper large-area nonmagnetic metal film 40 flows through the upper large-area nonmagnetic metal film 40 in parallel with the film plane because the upper large-area nonmagnetic metal film 40 is present in a wider area than

25 that of the GMR element 30, and the sensing current flows from the interface between the upper large-area nonmagnetic metal film 40 and the pinned magnetic layer 33 to the GMR element 30 perpendicularly to the film plane (in the

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thickness direction). Then, the sensing current flows into
the lower large-area nonmagnetic metal film 20 from the
interface between the free magnetic layer 31 and the lower
large-area nonmagnetic metal film 20. The sensing current

5 flowing into the lower large-area nonmagnetic metal film 20
is mostly flows through the lower large-area nonmagnetic
metal film 20 with lower resistivity in parallel with the
film plane because the lower large-area nonmagnetic metal
film 20 has lower resistivity than that of the lower shield

10 layer 10 and is present in a wider area than that of the GMR
element 30. The sensing current little flows through the
lower shield layer 10 disposed below the GMR element 30.

In this current path, the sensing current is not
concentrated above or below the range in which the GMR

15 element 30 is formed. Namely, the current density at each of
the interfaces between the large-area nonmagnetic metal films
20 and 40 and the shield layers 10 and 50 is decreased, and
even when an AMR effect of the shield layers 10 and 50 occurs,
noise (resistance change of the shield layers 10 and 50) due

20 to the AMR effect is thus suppressed. When the sensing
current is passed from the lower shield layer 10 to the upper
shied layer 50, the same current path as shown in Fig. 4 can
be formed except that the sensing current flows in the
opposite direction.

25 As described above, the antiferromagnetic layer 34 is
formed in the rear of the first pinned magnetic layer 33c in
the height direction, for pinning the magnetization direction
of the pinned magnetic layer 33 (the fist pinned magnetic

layer 33c), and thus the antiferromagnetic layer 34 is absent from the current path shown in Fig. 4. The antiferromagnetic layer 34 generally has significantly higher resistivity than those of the GMR element 30 and the large-area nonmagnetic

5 metal films 20 and 40, and the antiferromagnetic layer 34 is formed to a thickness of as large as 70 Å to 300 Å for obtaining antiferromagnetic characteristics, thereby producing great Joule heat when the current flows. Therefore, as in this embodiment, when the antiferromagnetic layer is

10 absent from the current path, the antiferromagnetic layer does not generate heat even when the sensing current flows, and thus the temperature of the head is not excessively increased to improve reliability. Also, since the antiferromagnetic layer is absent from the current path, the

15 high-frequency characteristics of the head are also improved.

In this embodiment, the antiferromagnetic layer is not provided in the current path, and thus the shield distance R-GL can be decreased, as compared with a conventional head. Furthermore, the upper and lower large-area nonmagnetic metal

20 films 20 and 40 can be formed in larger thicknesses t20 and t40, respectively, as compared with a conventional head. As shown in Fig. 55, in the conventional head, the antiferromagnetic layer is formed thickly on the pinned magnetic layer, and thus the thickness of the nonmagnetic

25 metal film cannot be sufficiently increased without increasing the shield distance R-GL'.

A method for manufacturing the CPP-GMR head 1 shown in Fig. 1 will be described below.

First, the lower shield layer 10, the lower large-area nonmagnetic metal film 20, the free magnetic layer 31, the nonmagnetic layer 32, the second pinned magnetic layer 33a, the nonmagnetic intermediate layer 33b, and the first pinned

5 magnetic layer 33c are continuously deposited in a solid form in vacuum in that order from below. The material and thickness of each layer are the same as in the completed CPP-GMR head 1 shown in Fig. 1.

Next, a liftoff resist layer is formed on the first

10 pinned magnetic layer 33c so as to cover an area substantially the same as or slightly smaller than the optical element area (track width dimension Tw and height dimension h1) of the GMR element 30 to be formed.

After the resist layer is formed, portions of the first

15 pinned magnetic layer 33c, the nonmagnetic intermediate layer 33b, the second pinned magnetic layer 33a, the nonmagnetic layer 32, and the free magnetic layer 31, which are not covered with the resist layer, are removed by ion milling or the like. In this step, the GMR element 30 having a

20 substantially trapezoidal shape having a track width dimension Tw and a height dimension h1 and comprising layers ranging from the free magnetic layer 31 to the first pinned magnetic layer 33c is left at the substantially center of the lower large-area nonmagnetic metal film 20 in the track width

25 direction. Since the substances removed by ion milling partially re-adhere to both sides of the GMR element 30, the re-adhering substances are preferably removed by milling again.

Then, the first insulating layers 61, the bias underlying layers 62, the hard bias layers 63 and the second insulating layers 64 are continuously deposited by sputtering on both sides of the GMR element 30. The material and

5   thickness of each layer are the same as in the completed CPP-GMR head 1 shown in Fig. 1. In sputtering deposition, the angle of sputtered particles is preferably about 90 degrees with the lower large-area nonmagnetic metal film 20. After sputtering deposition, the resist layer is removed.

10   After the resist layer is removed, the antiferromagnetic layer 34 is formed in the rear of the first pinned magnetic layer 33c in the height direction, as shown in Figs. 2 and 3. Namely, a resist layer having an aperture corresponding to an antiferromagnetic layer formation area is formed over the

15   first pinned magnetic layer 33c and the second insulating layers 64. Then, a portion of the second insulating films 64, which is not covered with the resist layer, is removed by ion milling, and the antiferromagnetic layer 43 is formed in the removed portion. After the antiferromagnetic layer 34 is

20   formed, the resist layer is removed.

Then, the GMR element 30 is annealed in a magnetic field in the height direction (the Y direction shown in the drawings) to produce an exchange coupling magnetic field between the antiferromagnetic layer 34 and the first pinned

25   magnetic layer 33c. For example, the annealing temperature is about 270° C, and the magnitude of the applied magnetic field is about 800 kA/m. In the annealing in the magnetic field, the magnetization direction of the first pinned

magnetic layer 33c is pinned in the height direction, and the magnetization direction of the second pinned magnetic layer 33a is pinned in antiparallel to the height direction.

After the annealing, as shown in Fig. 5, the upper large-area nonmagnetic metal film 40 is deposited over the first pinned magnetic layer 33c and the second insulating layers 64 by sputtering, and the upper surface of the upper large-area nonmagnetic metal film 40 is subjected to CMP or ion milling. In the CMP or ion milling, the upper surface of the upper large-area nonmagnetic metal film 40 is planarized. The material of the upper large-area nonmagnetic metal film 40 and the thickness t40 after CMP are the same as in the completed CPP-GMR head 1 shown in Fig. 1.

Then, the upper shield layer 50 is deposited by sputtering on the planarized upper large-area nonmagnetic metal film 40. The upper shield layer 50 may be deposited by sputtering in succession to the upper large-area nonmagnetic metal film 40 during the deposition of the upper large-area nonmagnetic metal film 40.

The CPP-GMR head 1 shown in Figs. 1 to 3 is completed by the above-described steps.

This embodiment comprises the metallic antiferromagnetic layer 34 comprising an antiferromagnetic material containing the element Z and Mn or an antiferromagnetic material containing the elements Z and Z' and Mn. However, an insulating antiferromagnetic layer comprising, for example, Ni-O or α-Fe$_2$O$_3$ may be used instead of the antiferromagnetic layer 34. The insulating antiferromagnetic layer can

suppress a sensing current loss to improve output. Also, in this embodiment, the upper large-area nonmagnetic metal film 40 is formed to cover the GMR element 30 and the second insulating layers 64. Therefore, the upper large-area

5   nonmagnetic metal film 40 can be subjected to CMP to secure flatness, and flatness can also be secured in laminating a recording inductive head on the upper shield layer 50.

Figs. 6 to 13 show a CPP giant magnetoresistive head (CPP-GMR head) according to a second embodiment of the

10   present invention.

The second embodiment is most different from the first embodiment in that the lower and upper large-area nonmagnetic metal films 20 and 40 of the first embodiment are replaced by lower and upper nonmagnetic metal films 220 and 240,

15   respectively, and the antiferromagnetic layer 34 in contact with the rear end surface of the second pinned magnetic layer in the height direction is replaced by an antiferromagnetic layer 234 in contact with the upper surface of a rear portion of a second pinned magnetic layer 231c which extends in the

20   height direction. In the second embodiment, even when the nonmagnetic metal films 220 and 240 are not present in a wide area, the generation of Joule heat can be suppressed because the antiferromagnetic layer 234 is absent from a region where the sensing current flows. Furthermore, a sufficient contact

25   area can be secured between the pinned magnetic layer 231 and the antiferromagnetic layer 234 to cause its own effect of more strongly pinning magnetization of the pinned magnetic layer 231.

Fig. 6 is a partial sectional view showing the structure of a CPP-GMR head 201, taken along a central line of a GMR element 230, Fig. 7 is a partial sectional view showing the structure of the CPP-GMR head 201 as viewed from a surface facing a recording medium, and Fig. 8 is a schematic top plan view of the GMR element 230. In Figs. 6 to 8, the functions, shapes, materials and thicknesses of layers denoted by the same reference numerals as those in the first embodiment shown in Figs. 1 to 3 are the same as those in the first embodiment, and thus the description thereof is omitted.

The CPP-GMR head 201 comprises the GMR element 230 exhibiting the GMR effect when a sensing current is passed through the upper shield layer 10 and the lower shield layer 50 in the thickness direction. In the GMR element 230, the lamination order of the layers is opposite to that in the GMR element 30 of the first embodiment. Namely, in this embodiment, a pinned magnetic layer 231 (a first pinned magnetic layer 231a, a nonmagnetic intermediate layer 231b, and a second pinned magnetic layer 231c), a nonmagnetic layer 232, and a free magnetic layer 233 are laminated in that order from below.

Each of the layers of the pinned magnetic layer 231 comprises a magnetic material having a positive magnetostriction constant, and the end surface of the pinned magnetic layer 231 is exposed at the surface facing the recording medium, as shown in Fig. 6. When the end surface is exposed at the surface facing the recording medium, the symmetry of two-dimensional isotropic stress applied to the

pinned magnetic layer 231 is broken to apply uniaxial tensile stress to the pinned magnetic layer 231 in parallel with the height direction. This inverse magnetostrictive effect stabilizes the magnetization direction of the pinned magnetic
5   layer 231 in a uniaxial direction parallel to the height direction.

As shown in Figs. 6 and 8, in the pinned magnetic layer 231, the first pinned magnetic layer 231a, the nonmagnetic intermediate layer 231b and a portion of the second pinned
10   magnetic layer 231c extend to the rear of the nonmagnetic layer 232 and the free magnetic layer 233 in the height direction, and the height dimension h2 is larger than the track width dimension Tw. Therefore, shape anisotropy parallel to the height direction occurs in each of the first
15   and second pinned magnetic layers 231a and 231c, and magnetization is also stabilized by the shape anisotropy in a uniaxial direction parallel to the height direction.

The thicknesses of the first pinned magnetic layer 231a and the nonmagnetic intermediate layer 231b are the same as
20   those of the first pinned magnetic layer 33c and the nonmagnetic intermediate layer 33b, respectively, in the first embodiment. In the second pinned magnetic layer 231c, a portion (a rear region in the height direction) outside the element has a smaller thickness than that within the element.
25   In this embodiment, the thickness of the portion within the element is about 50 Å, and the thickness of the portion outside the element is about 40 Å.

The lower nonmagnetic metal film 220 is formed

immediately below the first pinned magnetic layer 231a to have a longer length than that of the first pinned magnetic layer 231a in the track width direction and substantially the same length as that of the first pinned magnetic layer 231a

5   in the height direction. The lower nonmagnetic metal film 220 functions as an electrode together with the lower shield layer 10 and also functions as a seed layer for regularly forming each of the layers constituting the GMR element 230. The crystal grain size and crystal orientation of each of the

10   layers of the GMR element 230 are controlled by the lower nonmagnetic metal film 220. The magnetization of each of the first and second pinned magnetic layers 231a and 231c is strengthened by the seed effect of the lower nonmagnetic metal film 220. The lower nonmagnetic metal film 220 may

15   comprise the same nonmagnetic metallic material as that used for the lower large-area nonmagnetic metal film 20 of the first embodiment, and the thickness of the lower nonmagnetic metal film 220 is smaller than that of the lower large-area nonmagnetic metal film 20. In this embodiment, the lower

20   nonmagnetic metal film 220 has a Ta/Cr two-layer structure.

The upper nonmagnetic metal film 240 is formed on the free magnetic layer 233 to have the same area as that of the free magnetic layer 233. The upper nonmagnetic metal film 240, a portion of the upper shield layer 50, the free

25   magnetic layer 233, the nonmagnetic layer 232 and a portion of the second pinned magnetic layer 231c have a smoothly continuous rear end surface in the height direction. The upper nonmagnetic metal film 240 may comprise the same

nonmagnetic metallic material as that used for the upper

large-area nonmagnetic metal film 40 of the first embodiment,

and the thickness is smaller than that of the upper large-

area nonmagnetic metal film 40.

5   In the CPP-GMR head 201, the antiferromagnetic layer 234

for pinning the magnetization direction of the pinned

magnetic layer 231 is provided in contact with the upper

surface of the rear portion of the second pinned magnetic

layer 231c in the rear of the GMR element in the height

10   direction.   Namely, the antiferromagnetic layer 234 is formed

on the rear portion of the second pinned magnetic layer 231c

which extends in the height direction, to make contact with

the rear end surfaces of the upper nonmagnetic metal film 240,

the free magnetic layer 233, the nonmagnetic layer 232, and a

15   portion of the second pinned magnetic layer 231c in the

height direction.   The material and thickness of the

antiferromagnetic layer 234 are the same as those of the

antiferromagnetic layer 34 of the first embodiment.

The antiferromagnetic layer 234 produces an exchange

20   coupling magnetic field at the interface with the second

pinned magnetic layer 231c, so that the magnetization

direction of the second pinned magnetic layer 231c is pinned

in the height direction by the exchange coupling magnetic

field.   The first and second pinned magnetic layers 231a and

25   231c have antiparallel magnetization directions due to a RKKY

interaction through the nonmagnetic intermediate layer 231b.

Therefore, magnetization of the first pinned magnetic layer

231a is pinned in antiparallel to the height direction.   In

this embodiment, the magnetic moment per unit area
(saturation magnetization Ms × thickness t) of the first
pinned magnetic layer 231a is larger than that of the second
pinned magnetic layer 231c, and thus the magnetization
direction of the whole pinned magnetic layer 231 is the same
as that of the first pinned magnetic layer 231a. In Fig. 6,
the magnetization direction of the first pinned magnetic
layer 231a is shown by a bold arrow, and the magnetization
direction of the second pinned magnetic layer 231c is shown
by a thin arrow.

As described above, in this embodiment, magnetization of
each of the first and second pinned magnetic layers 231a and
231c is strongly pinned by uniaxial anisotropy due to the
inverse magnetostrictive effect, shape anisotropy, and the
seed effect of the lower nonmagnetic metal film 220.

Furthermore, a first backfill gap layer (insulating
layer) 271 comprising an insulating material such as Al_2O_3 or
SiO_2 is formed between the antiferromagnetic layer 234 and
the upper shield layer 50, for preventing the sensing current
from flowing toward the antiferromagnetic layer 234. As
shown in Fig. 6, the first backfill gap layer 271, the
antiferromagnetic layer 234, the second pinned magnetic layer
231c, the nonmagnetic intermediate layer 231b, the first
pinned magnetic layer 231a and the lower nonmagnetic metal
film 220 have the respective rear end surfaces at the same
position in the height direction. In the rear of the first
backfill gap layer 271, the antiferromagnetic layer 234, the
second pinned magnetic layer 231c, the nonmagnetic

intermediate layer 231b, the first pinned magnetic layer 231a

and the lower nonmagnetic metal film 220 in the height

direction, the space between the lower shield layer 10 and

the upper shield layer 50 is filled with a second backfill

5 gap layer (insulating layer) 272 comprising an insulating

material such as Al_2O_3 or SiO_2.

Next, a method for manufacturing the CPP-GMR head 201

shown in Figs. 6 to 8 according to an embodiment of the

present invention will be described below with reference to

10 Figs. 9 to 12.

In Figs. 9 to 12, Fig. A is a partial sectional view

showing a step for manufacturing the CPP-GMR head 201, as

viewed from the surface facing the recording medium, and Fig.

B is a partial sectional view showing a step for

15 manufacturing the CPP-GMR head 201 taken along a central line

of the element in parallel with the height direction. Since

the material and thickness of each layer are the same as

those of the completed CPP-GMR head 201, the description

thereof is omitted.

20 First, the lower nonmagnetic metal film 220, the first

pinned magnetic layer 231a, the nonmagnetic intermediate

layer 231b, the second pinned magnetic layer 231c, the   •

nonmagnetic layer 232, the free magnetic layer 233, and the

upper nonmagnetic metal film 240 are continuously deposited

25 on the lower shield layer 10 in vacuum in that order from

below. These layers are deposited by sputtering. In this

deposition, the second pinned magnetic layer 231c is

uniformly deposited to the same thickness as that of the

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element portion of the completed second pinned magnetic layer 231c within the element.

Next, a resist layer R1 is formed on the upper nonmagnetic metal film 240, for determining the track width dimension Tw of the GMR element 230 to be formed.

After the resist layer R1 is formed, portions of the layers ranging from the upper nonmagnetic metal film 240 to the first pinned magnetic layer 231a (the upper nonmagnetic metal film 240, the free magnetic layer 233, the nonmagnetic layer 232, the second pinned magnetic layer 231c, the nonmagnetic intermediate layer 231b, and the first pinned magnetic layer 231a) which are not covered with the resist layer R1, are removed by ion milling, for example. The ion milling is stopped when the lower nonmagnetic metal film 220 is exposed. In this step, as shown in Fig. 9, the GMR element 230 comprising the layers ranging from the first pinned magnetic layer 231a to the free magnetic layer 233, and the upper nonmagnetic metal film 240 are left on the lower nonmagnetic metal film 220 at the substantially center thereof in the track width direction. Since the substances removed by ion milling partially re-adhere to both sides of the GMR element 230, the re-adhering substances are preferably removed by milling again.

Then, as shown in Fig. 10, the first insulating layers 61, the bias underlying layers 62, the hard bias layers 63 and the second insulating layers 64 are continuously deposited by sputtering on both sides of the GMR element 230. These layers are deposited by sputtering. In sputtering

deposition, the angle of sputtered particles is preferably about 90 degrees with the lower nonmagnetic metal film 220. After sputtering deposition, the resist layer R1 is removed.

After the resist layer R1 is removed, a resist layer R2
5   is formed on the upper nonmagnetic metal film 240, for determining the height dimension h1 of the GMR element 230 to be formed.

Then, as shown in Fig. 11, portions of the upper nonmagnetic metal film 240, the free magnetic layer 233, the
10 nonmagnetic layer 232 and a portion of the second pinned magnetic layer 231c, which are not covered with the resist layer R2, are removed by, for example, ion milling, and the antiferromagnetic layer 234 and the first backfill gap layer 271 are deposited in the removed portion.

15   In the ion milting step, the upper nonmagnetic metal film 240, the free magnetic layer 233 and the nonmagnetic layer 232 are left only in the element portion used as the GMR element 230, and a portion of the second pinned magnetic layer 231c, the nonmagnetic intermediate layer 231b and the
20 first pinned magnetic layer 231a are left to extend to the rear of the free magnetic layer 233 and the nonmagnetic layer 232 in the height direction. The upper nonmagnetic metal film 240, a portion of the upper shield layer 50, the free magnetic layer 233, the nonmagnetic layer 232 and a portion
25 of the second pinned magnetic layer 231c have a smoothly continuous rear end surface in the height direction. In the second pinned magnetic layer 231c, a portion (rearwardly extending in the height direction) outside the element has a

smaller thickness than that of a portion within the element.

After the first backfill gap layer 271 is deposited, the resist layer R2 is removed by liftoff.

After the resist layer R2 is removed, a resist layer R3
5   is formed on the nonmagnetic metal film 240 and the first backfill gap layer 271, for determining the height dimension h2 of the second pinned magnetic layer 231c, the nonmagnetic intermediate layer 231b and the first pinned magnetic layer 231a. The height dimension h2 is set to be larger than the
10 track width dimension Tw and the height dimension h1 of the GMR element 230. The resist layer R3 has a dimension larger than that of the resist layer R2 in the height direction.

Then, as shown in Fig. 12, portions of the layers ranging from the first backfill gap layer 271 to at least the
15 first pinned magnetic layer 231a, which are not covered with the resist layer R3, are removed by ion milling. In this embodiment, portions of the first backfill gap layer 271, the antiferromagnetic layer 234, a portion of the second pinned magnetic layer 231c, the nonmagnetic intermediate layer 231b,
20 the first pinned magnetic layer 231a, and the lower nonmagnetic metal film 220, which are not covered with the resist layer R3, are removed to expose the lower shield layer 10 in the removed portion. As shown in Fig. 12, the second backfill gap layer 272 is deposited on the exposed portion of
25 the lower shield layer 10. After the second backfill gap layer 272 is deposited, the resist layer R3 is removed by liftoff.

After the resist layer R3 is removed, annealing is

performed in a magnetic field in the height direction. The

annealing temperature is about 270°C, and the magnitude of

the applied magnetic field is about 800 kA/m. In the

annealing in the magnetic field, at least a portion of the

5   antiferromagnetic layer 234 is transformed from a disordered

lattice to an ordered lattice to exhibit antiferromagnetic

characteristics. Namely, an exchange coupling magnetic field

occurs between the antiferromagnetic layer 234 and the second

pinned magnetic layer 231c. The magnetization direction of

10   the second pinned magnetic layer 231c is pinned by the

produced exchange coupling magnetic field in the height

direction, and the magnetization direction of the first

pinned magnetic layer 231a is pinned in antiparallel to the

height direction. In Fig. 6, the magnetization direction of

15   each of the first and second pinned magnetic layers 231a and

231c is shown by an arrow.

In this embodiment, the antiferromagnetic layer 234 is

in contact with the upper surface of the rear portion of the

second pinned magnetic layer 231c which extends in the height

20   direction, and thus a contact area (an area where an exchange

coupling magnetic field occurs) can be sufficiently secured

between the antiferromagnetic layer 234 and the second pinned

magnetic layer 231c to strongly pin magnetization of the

second pinned magnetic layer 231c. Therefore, magnetization

25   of the first pinned magnetic layer 231a is also strongly

pinned through the nonmagnetic intermediate layer 231b.

After the annealing, the upper shield layer 50 is

deposited over the upper nonmagnetic metal film 240, the

second insulating layers 64, the first backfill gap layer 271 and the second backfill gap layer 272. The upper nonmagnetic metal film 240 may be deposited immediately before the deposition of the upper shield layer 50.

5   The CPP-GMR head 201 shown in Figs. 6 to 8 is completed by the above-described steps.

As described above, in the second embodiment, the antiferromagnetic layer 234 is provided in contact with the upper surface of the rear portion of the second pinned

10   magnetic layer 231c which extends in the height direction beyond the element portion (the nonmagnetic layer 232 and the free magnetic layer 233), for producing an exchange coupling magnetic field between the upper surface of the second pinned magnetic layer 231c and the antiferromagnetic layer 234.

15   Therefore, a wider contact area (an area where an exchange coupling magnetic field occurs) can be secured between the second pinned magnetic layer 231c and the antiferromagnetic layer 234 to stably and strongly pin magnetization of the pinned magnetic layer, as compared with the case in which the

20   antiferromagnetic layer is provided in contact with the rear end surface of the first or second pinned magnetic layer 231a or 231c in the height direction like in the first embodiment. The contact area between the second pinned magnetic layer 231c and the antiferromagnetic layer 234 is 500 times or more

25   as large as that between the first pinned magnetic layer 33c and the antiferromagnetic layer 34 in the first embodiment. In the second embodiment, the contact area between the antiferromagnetic layer and the pinned magnetic layer is

defined by the track width dimension Tw and the height
dimension h (= h2 - h1), while in the first embodiment, the
contact area is defined by the track width dimension Tw and
the thickness of the first pinned magnetic layer 33c.

5   In the second embodiment, the pinned magnetic layer 231
comprises a magnetic material having a positive
magnetostriction constant, and the end surface of the pinned
magnetic layer 231 is exposed at the surface facing the
recording medium. Therefore, magnetization pinning of the
10   first and second pinned magnetic layers 231a and 231c is also
strengthened by the inverse magnetostrictive effect.
Furthermore, since the length of the pinned magnetic layer
231 in the height direction is larger than that in the track
width direction (Tw < h2), magnetization pinning of the first
15   and second pinned magnetic layers 231a and 231c is also
strengthened by shape anisotropy. Furthermore, since each of
the layers constituting the GMR element 230 is formed above
the lower nonmagnetic metal film 220 having the two-layer
structure comprising Ta/Cr, magnetization pinning of the
20   first and second pinned magnetic layers 231a and 231c is also
strengthened by the seed effect of the lower nonmagnetic
metal film 220.

In the second embodiment, when the sensing current flows
from the upper shield layer 50 to the lower shield layer 10
25   perpendicularly (in the thickness direction) to the film
plane of the GMR element 230, a sensing current magnetic
field occurs in the clockwise direction shown by an arrow in
Fig. 13. In order to further strengthen magnetization

pinning of the pinned magnetic layer 231, the direction of
the sensing current magnetic field is preferably the same as
that of a synthetic magnetic moment (shown by bold arrows in
Fig. 13) of the first and second pinned magnetic layers 231a
and 231c. However, even if the direction of the sensing
current magnetic field is not the same as that of the
synthetic magnetic moment of the first and second pinned
magnetic layers 231a and 231c, magnetization of the pinned
magnetic layer 231 is not fluctuated by the generated sensing
current magnetic field as far as magnetization of the pinned
magnetic layer 231 is sufficiently strongly pinned like in
the second embodiment. Therefore, the sensing current
density can be increased to increase output.

　　　　Like in the first embodiment, in the second embodiment,
the antiferromagnetic layer 234 is disposed in the rear of
the GMR element 230 in the height direction, and thus the
antiferromagnetic layer 234 is separated from the current
path in which the sensing current flows. Therefore, even
when the sensing current is passed, the antiferromagnetic
layer 234 does not generate heat to significantly decrease
the heat generation from the GMR element 230 during the
operation. As a result, an increase in the element
temperature is suppressed to improve reliability. In the
second embodiment, the upper surface of the antiferromagnetic
layer 234 is positioned above the upper surface of the GMR
element 230. However, the upper surface of the
antiferromagnetic layer 234 is covered with the first
backfill gap layer 271, and thus the sensing current little

flows through the antiferromagnetic layer 234, thereby decreasing a shunt loss and improving reproduction output.

When the antiferromagnetic layer 234 is disposed in the rear of the GMR element 230 in the height direction, the shield distance R-GL at the surface facing the recording medium can be decreased in comparison to the conventional head shown in Fig. 55, thereby improving resolution.

In this embodiment, like the upper and lower large-area nonmagnetic metal films 20 and 40 of the first embodiment, each of the nonmagnetic metal films 220 and 240 may be formed to a large thickness in a wide area.

Figs. 14 to 19 show a CPP giant magnetoresistive head (CPP-GMR heat) according to a third embodiment of the present invention.

The third embodiment is different from the second embodiment in that an antiferromagnetic layer 334 is provided in contact with the lower surface of a first pinned magnetic layer, not the upper surface of a second pinned magnetic layer. The third embodiment is the same as the second embodiment except the arrangement position of the antiferromagnetic layer.

Fig. 14 is a partial sectional view showing the structure of a CPP-GMR head 301, taken along a central line of an element, Fig. 15 is a partial sectional view showing the structure of the CPP-GMR head 301, as viewed from a surface facing a recording medium, and Fig. 16 is a schematic top plan view of a GMR element 330. In Figs. 14 to 16, the functions, materials and thicknesses of layers denoted by the

same reference numerals as those in the second embodiment shown in Figs. 6 to 8 are the same as those in the second embodiment, and thus the description thereof is omitted.

The CPP-GMR head 301 comprises the GMR element 330
5   exhibiting the GMR effect when a sensing current is passed through the upper shield layer 10 and the lower shield layer 50 in the thickness direction. Like in the GMR element 230 of the second embodiment, in the GMR element 330, a pinned magnetic layer 331 (a first pinned magnetic layer 331a, a
10 nonmagnetic intermediate layer 331b, and a second pinned magnetic layer 331c), a nonmagnetic layer 332, and a free magnetic layer 333 are laminated in that order from below. The shapes, thicknesses and materials of the nonmagnetic layer 332 and the free magnetic layer 333 are the same as
15 those of the nonmagnetic layer 232 and the free magnetic layer 233, respectively, of the second embodiment.

Like the pinned magnetic layer 231 of the second embodiment, each of the layers of the pinned magnetic layer 331 comprises a magnetic material having a positive
20 magnetostriction constant, and the end surface of the pinned magnetic layer 331 is exposed at the surface facing the recording medium, as shown in Fig. 14. Therefore, the magnetization direction of the pinned magnetic layer 331 is stabilized by the inverse magnetostrictive effect in a
25 direction parallel to the height direction.

As shown in Figs. 14 and 16, in the pinned magnetic layer 331, the first pinned magnetic layer 331a, the nonmagnetic intermediate layer 331b and a portion of the

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second pinned magnetic layer 331c extend to the rear of the

nonmagnetic layer 332 and the free magnetic layer 333 in the

height direction, and the height dimension h2 is larger than

the track width dimension Tw. Therefore, shape anisotropy

5   parallel to the height direction occurs in each of the first

and second pinned magnetic layers 331a and 331c, and

magnetization is also stabilized by the shape anisotropy in a

direction parallel to the height direction.

The first pinned magnetic layer 331a is formed over the

10 lower nonmagnetic metal film 220 and the antiferromagnetic

layer 334 to form a step which covers the upper surface and

the end surface (left end shown in Fig. 14) of the

antiferromagnetic layer 334.   The nonmagnetic intermediate

layer 331b and a portion of the second pinned magnetic layer

15 331c are laminated on the first pinned magnetic layer 331a to

form the same step as that of the first pinned magnetic layer

331a.

The thicknesses of the first pinned magnetic layer 331a,

the nonmagnetic intermediate layer 331b, and the second

20 pinned magnetic layer 331c are the same as those of the first

pinned magnetic layer 231a, the nonmagnetic intermediate

layer 231b, and the second pinned magnetic layer 231c,

respectively, in the second embodiment.   In this embodiment,

the magnetic moment per unit area of the first pinned

25 magnetic layer 331a is larger than that of the second pinned

magnetic layer 331c.

The antiferromagnetic layer 334 is formed on the lower

nonmagnetic metal film 220 to make contact with the first

pinned magnetic layer 331a (at the left end shown in Fig. 14) and disposed in the rear of the element portion (the nonmagnetic layer 332 and the free magnetic layer 333) in the height direction. The antiferromagnetic layer 334 produces

5   an exchange coupling magnetic field at the interface with the first pinned magnetic layer 331a, so that the magnetization direction of the first pinned magnetic layer 331a is pinned in antiparallel to the height direction by the exchange coupling magnetic field. The first and second pinned

10   magnetic layers 331a and 331c have antiparallel magnetization directions due to a RKKY interaction through the nonmagnetic intermediate layer 331b. Therefore, magnetization of the second pinned magnetic layer 331c is pinned in the height direction. In this embodiment, the magnetic moment per unit

15   area of the first pinned magnetic layer 331a is larger than that of the second pinned magnetic layer 331c, and thus the magnetization direction of the whole pinned magnetic layer 331 is the same as that of the first pinned magnetic layer 331a. In Fig. 14, the magnetization direction of the first

20   pinned magnetic layer 331a is shown by a bold arrow, and the magnetization direction of the second pinned magnetic layer 331c is shown by a thin arrow.

The antiferromagnetic layer 334 can be formed to the same thickness using the same material as the

25   antiferromagnetic layer 234 of the second embodiment. In the lower nonmagnetic metal film 220, a portion on which the first pinned magnetic layer 331a is formed has a smaller thickness than that of a portion on which the

antiferromagnetic layer 334 is formed.

Furthermore, a backfill gap layer 370 comprising an insulating material such as Al_2O_3 or SiO_2 is formed between the second pinned magnetic layer 331c and the upper shield

5 layer 50, for preventing the sensing current from flowing directly to the second pinned magnetic layer 331c. The backfill gap layer 370 is formed in contact with the rear end surfaces of the nonmagnetic layer 332, the free magnetic layer 333 and the upper nonmagnetic metal film 240 in the

10 height direction.

Next, a method for manufacturing the CPP-GMR head 301 shown in Figs. 14 to 16 according to an embodiment of the present invention will be described below with reference to Figs. 17 to 19. Each of Figs. 17 to 19 is a partial

15 sectional view showing a step for manufacturing the CPP-GMR head 301, taken along a central line of the element in parallel with the height direction. The material and thickness of each layer are the same as those of the completed CPP-GMR head 301.

20 First, the lower nonmagnetic metal film 220 and the antiferromagnetic layer 334 are continuously deposited on the lower shield layer 10 in vacuum in that order from below. These layers are deposited by sputtering. Like in the second embodiment, in this embodiment, the lower nonmagnetic metal

25 film 220 has a two-layer structure comprising Ta/Cr.

Next, a resist layer is formed on the antiferromagnetic layer 334, for determining the planar size of the antiferromagnetic layer 334, and portions of the

antiferromagnetic layer 334 and a portion of the Cr film of

the lower nonmagnetic metal film 220, which are not covered

with the resist layer, are removed by ion milling, for

example. Then, the resist layer is removed by liftoff. In

5   this step, as shown in Fig. 17, the antiferromagnetic layer

334 is left only on a rear portion of the lower nonmagnetic

metal film 220 in the height direction.

After the resist layer is removed, the surfaces of the

lower nonmagnetic metal film 220 and the antiferromagnetic

10   layer 334 are cleaned as a pre-treatment of a subsequent

deposition step.

Then, as shown in Fig. 18, the first pinned magnetic

layer 331a, the nonmagnetic intermediate layer 331b, the

second pinned magnetic layer 331c, the nonmagnetic layer 332,

15   the free magnetic layer 333 and the upper nonmagnetic metal

film 240 are continuously deposited in vacuum on the cleaned

lower nonmagnetic metal film 220 and antiferromagnetic layer

334. These layers are deposited by sputtering. Since a

large step occurs between the top of the lower nonmagnetic

20   metal film 220 and the top of the antiferromagnetic layer 334,

a step also occurs in a rear portion in the height direction

of each of the layers ranging from the first pinned magnetic

layer 331a to the upper nonmagnetic metal film 240. The

second pinned magnetic layer 331c is formed to the same

25   thickness as that of the element portion of the completed

second pinned magnetic layer 331c.

Then, a resist layer is formed on the upper nonmagnetic

metal film 240, for determining the track width dimension Tw

of the GMR element 330 to be formed.

After the resist layer is formed, portions of the upper nonmagnetic metal film 240, the free magnetic layer 333, the nonmagnetic layer 332, the second pinned magnetic layer 331c, the nonmagnetic intermediate layer 331b, and the first pinned magnetic layer 331a, which are not covered with the resist layer, are removed by, for example, ion milling, and ion milling is stopped when the lower nonmagnetic metal film 220 is exposed. In the ion milting step, the upper nonmagnetic metal film 240, and the GMR element 330 ranging from the first pinned magnetic layer 331a to the free magnetic layer 333 are left on the lower nonmagnetic metal film 220 at the substantially center in the track width direction. Since the substances removed by ion milling partially re-adhere to both sides of the GMR element 330, the re-adhering substances are preferably removed by milling again.

Then, in the state in which the resist layer remains, the first insulating layers 61, the bias underlying layers 62, the hard bias layers 63, and the second insulating layers 64 are continuously deposited on both sides of the GMR element 330. These layers are deposited by sputtering. In sputtering deposition, the angle of sputtered particles is preferably about 90 degrees with the lower nonmagnetic metal film 220. After sputtering deposition, the resist layer is removed by liftoff.

After the resist layer is removed, a new resist layer is formed on the upper nonmagnetic metal film 240, for determining the height dimension h1 of the GMR element 330 to

be formed.

Then, portions of the upper nonmagnetic metal film 240,
the free magnetic layer 333, the nonmagnetic layer 332, and a
portion of the second pinned magnetic layer 331c, which are

5   not covered with the resist layer, are removed by, for
example, ion milling, and the backfill gap layer 370 is
deposited in the removed portion. After the backfill gap
layer 370 is deposited, the resist layer is removed by
liftoff.

10   As shown in Fig. 19, in the ion milling step, the upper
nonmagnetic metal film 240, the free magnetic layer 333 and
the nonmagnetic layer 332 are left only in the element
portion used as the GMR element 330. On the other hand, a
part of the second pinned magnetic layer 331c, the

15   nonmagnetic intermediate layer 331b and the first pinned
magnetic layer 331a extend to the rear of the free magnetic
layer 333 and the nonmagnetic layer 332 in the height
direction, and the steps formed during deposition are also
left. In the second pinned magnetic layer 331c, a portion

20   (rearwardly extending in the height direction) outside the
element has a smaller thickness than that of the element
portion.

After the resist layer is removed, annealing is
performed in a magnetic field antiparallel to the height

25   direction to produce an exchange coupling magnetic field
between the antiferromagnetic layer 334 and the first pinned
magnetic layer 331a. The annealing temperature is about
270° C, and the magnitude of the applied magnetic field is

about 800 kA/m.   In the annealing in the magnetic field, the

magnetization direction of the first pinned magnetic layer

331a is pinned in antiparallel to the height direction, and

the magnetization direction of the second pinned magnetic

5   layer 331c is pinned in the height direction.   In Fig. 14,

the magnetization direction of each of the first and second

pinned magnetic layers 331a and 331c is shown by an arrow.

In this embodiment, the antiferromagnetic layer 334 is

covered with the lower surface of the rear portion of the

10   first pinned magnetic layer 331a which extends in the height

direction, and thus a contact area (an area where an exchange

coupling magnetic field occurs) can be sufficiently secured

between the antiferromagnetic layer 334 and the first pinned

magnetic layer 331a to strongly pin magnetization of the

15   first pinned magnetic layer 331a.   Therefore, magnetization

of the second pinned magnetic layer 331c is also strongly

pinned through the nonmagnetic intermediate layer 331b.

          After the annealing, the upper surfaces of the upper

nonmagnetic metal film 240, the second insulating layers 64

20   and the backfill gap layer 370 are planarized by, for example,

CMP or ion milling as a pre-treatment for forming the upper

shield layer 50.   Then, the upper shield layer 50 is

deposited over the planarized surfaces of the upper

nonmagnetic metal film 240, the second insulating layers 64,

25   and the backfill gap layer 370.

          The CPP-GMR head 301 shown in Figs. 14 to 16 is

completed by the above-described steps.

          As described above, in the third embodiment, the

antiferromagnetic layer 334 is provided in contact with the
lower surface of the rear portion of the first pinned
magnetic layer 331a which extends in the height direction
beyond the element portion (the nonmagnetic layer 332 and the
5   free magnetic layer 333), for producing an exchange coupling
magnetic field between the lower surface of the first pinned
magnetic layer 331a and the antiferromagnetic layer 334.
Therefore, like in the second embodiment, a wider contact
area (an area where an exchange coupling magnetic field
10   occurs) can be secured between the first pinned magnetic
layer 331a and the antiferromagnetic layer 334 to stably and
strongly pin magnetization of the pinned magnetic layer. The
contact area between the first pinned magnetic layer 331a and
the antiferromagnetic layer 334 is larger that in the case in
15   which the antiferromagnetic layer is in contact with the rear
end surface of any one of the first pinned magnetic layer and
the second pinned magnetic layer like in the first embodiment.
In the second embodiment, the contact area between the first
pinned magnetic layer 331a and the antiferromagnetic layer
20   334 is 500 times or more as large as that between the first
pinned magnetic layer 33c and the antiferromagnetic layer 34
in the first embodiment. In the third embodiment, the
contact area between the antiferromagnetic layer and the
pinned magnetic layer is defined by the dimension in the
25   track width direction, the height dimension, and the
thickness of the antiferromagnetic layer 334.

    Like in the second embodiment, in the third embodiment,
magnetization pinning of the first and second pinned magnetic

layers 331a and 331c is also strengthened by uniaxial

anisotropy due to the inverse magnetostrictive effect, shape

anisotropy, and the seed effect of the lower nonmagnetic

metal film 220. In this way, when magnetization of each of

5   the first pinned magnetic layer 331a and the second pinned

magnetic layer 331c is strongly pinned, magnetization of the

pinned magnetic layer 331 is not fluctuated by the generated

sensing current magnetic field even if the direction of the

sensing current magnetic field is not the same as that of the

10   synthetic magnetic moment of the first and second pinned

magnetic layers 331a and 331c. Therefore, the sensing

current density can be increased to increase output.

Like in the first and second embodiments, in the third

embodiment, even when the sensing current is passed through

15   the GMR element 330, the antiferromagnetic layer 334 does not

generate heat, and an increase in the element temperature is

suppressed to improve reliability. Also, the shield distance

R-GL at the surface facing the recording medium can be

decreased in comparison to the conventional head shown in Fig.

20   55, thereby improving resolution.

Figs. 20 to 25 show a CPP giant magnetoresistive head

(CPP-GMR heat) according to a fourth embodiment of the

present invention.

Fig. 20 is a partial sectional view showing the

25   structure of a CPP-GMR head 401, taken along a central line

of an element, Fig. 21 is a partial sectional view showing

the structure of the CPP-GMR head 401, as viewed from a

surface facing a recording medium, and Fig. 22 is a schematic

top plan view of a GMR element 330. In Figs. 20 to 25, the functions, materials and thicknesses of layers denoted by the same reference numerals as those in the third embodiment shown in Figs. 14 to 16 are the same as those in the third

5 embodiment.

In the fourth embodiment, in the CPP-GMR head 301 of the third embodiment, a magnetostrictive enhancement layer 434 is interposed between the lower nonmagnetic metal film 220 and the first pinned magnetic layer 331a and between the

10 antiferromagnetic layer 334 and the first pinned magnetic layer 331a. The magnetostrictive enhancement layer 434 has the function to produce crystal mismatching at the interface with the first pinned magnetic layer 331a and increase the magnetostriction constant of the first pinned magnetic layer

15 331a due to the distortion of the crystal structure. When the magnetostriction constant of the first pinned magnetic layer 331a is increased, magnetization of each of the first pinned magnetic layer 331a and the second pinned magnetic layer 331c can be more strongly pinned to increase output and

20 improve output stability and symmetry.

The magnetoresistive enhancement layer 434 and the antiferromagnetic layer 334 comprise a Z-Mn alloy (wherein Z is at least one element of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe). When the magnetoresistive enhancement layer 434

25 comprises this material, it has a face-centered cubic structure (fcc) at least at the interface with the first pinned magnetic layer 331a, and an equivalent crystal plane represented by {111} plane is preferentially oriented in

parallel with the interface.

The magnetoresistive enhancement layer 434 is formed to a thickness of 5 Å to 50 Å. With a thickness in this range, a disordered lattice cannot be transformed to an ordered

5   lattice even by a heat treatment because of its small thickness, and the face-centered cubic structure (fcc) at the time of deposition is maintained. When the magnetoresistive enhancement layer 434 has a face-centered cubic crystal structure (fcc), the magnetoresistive enhancement layer 434

10   does not exhibit the antiferromagnetic characteristics, and thus no or weak exchange coupling magnetic field occurs at the interface between the magnetoresistive enhancement layer 434 and the first pinned magnetic layer 331a. When the magnetoresistive enhancement layer 434 has a thickness of

15   over 50 Å, the structure is transformed to a CuAuI-type ordered face-centered tetragonal structure (fct) by heating to about 250° C or more, like the antiferromagnetic layer 334. However, even when the thickness of the magnetoresistive enhancement layer 434 exceeds 50 Å, the magnetoresistive

20   enhancement layer 434 maintains the face-centered cubic crystal structure (fcc) unless heat of 250° C or more is applied.

The magnetostrictive enhancement layer 434 is epitaxially or heteroepitaxially matched with the first

25   pinned magnetic layer 331a to appropriately distort the crystal structures.

As described above, the magnetostrictive enhancement layer 434 of this embodiment has the face-centered cubic

structure (fcc) in which an equivalent crystal plane represented by {111} plane is preferentially oriented in parallel with the interface with the first pinned magnetic layer 331a. On the other hand, the first pinned magnetic

5 layer 331a comprises Co or Co_mFe_n (n ≤ 20 and n+m = 100) and has the face-centered cubic structure (fcc) in which an equivalent crystal plane represented by {111} plane is preferentially oriented in parallel with the interface with the magnetostrictive enhancement layer 434. Therefore, the

10 constituent atoms of the magnetostrictive enhancement layer 434 easily overlap the constituent atoms of the first pinned magnetic layer 331a, and the crystals in the magnetostrictive enhancement layer 434 and the first pinned magnetic layer 331a are epitaxially matched with each other. However, in

15 order to distort the crystal structures, a predetermined difference or more must be produced between the nearest neighbor interatomic distance N2 in {111} plane of the magnetostrictive enhancement layer 434 and the nearest neighbor interatomic distance N1 in {111} plane of the first

20 pinned magnetic layer 331a. As schematically shown in Fig. 23, in this embodiment, the constituent atoms of the magnetostrictive enhancement layer 434 overlap the constituent atoms of the first pinned magnetic layer 331a while distorting the crystal structures near the interface

25 therebetween.

In this embodiment, the Z element content of the Z-Mn alloy used for forming the magnetostrictive enhancement layer 434 is controlled to 40 atomic percent to 95 atomic percent.

Within this range, the first pinned magnetic layer 331a takes a positive large value of magnetostriction constant and is stabilized.

Next, a method for manufacturing the CPP-GMR head 401

5 shown in Figs. 20 to 22 according to an embodiment of the present invention will be described below with reference to Figs. 24 and 25. Each of Figs. 24 and 25 is a partial sectional view showing a step for manufacturing the CPP-GMR head 401, taken along a central line of an element in

10 parallel with the height direction. Since the material and thickness of each layer are the same as those of the completed CPP-GMR head 401, the description thereof is omitted.

First, the lower nonmagnetic metal film 220 having a

15 Ta/Cr two-layer structure is deposited on the lower shield layer 10. Next, a resist layer having an aperture for forming an antiferromagnetic layer is formed on the lower nonmagnetic metal film 220, and a portion (a portion of the Cr film) of the lower nonmagnetic metal film 220, which is

20 not covered with the resist, is removed by ion milling. Then, as shown in Fig. 24, the antiferromagnetic layer 334 and a Re layer 440 are continuously deposited with the resist left on the lower nonmagnetic metal film 220. These layers are deposited by sputtering. The Ru layer 440 is deposited to a

25 thickness of as small as about 5 Å to 10 Å to functions as an antioxidative layer for the antiferromagnetic layer 334. After the Ru layer 440 is deposited, the resist is removed by liftoff.

Then, the Ru layer 440 deposited on the antiferromagnetic layer 334 is removed by, for example, ion beam etching with low ion energy, and at the same time, the oxide layer produced on the lower nonmagnetic metal film 220 is removed.

Then, as shown in Fig. 25, the magnetostrictive enhancement layer 434, the first pinned magnetic layer 331a, the nonmagnetic intermediate layer 331b, the second pinned magnetic layer 331c, the nonmagnetic layer 332, the free magnetic layer 333 and the upper nonmagnetic metal film 240 are continuously deposited over the lower nonmagnetic metal film 220 and the antiferromagnetic layer 334. In this embodiment, the magnetostrictive enhancement layer 434 and the first pinned magnetic layer 331a are epitaxially matched with each other, and the structure of each of the magnetoresistive enhancement layer 434 and the first pinned magnetic layer 331a is distorted at the interface therebetween.

Since the steps after the upper nonmagnetic metal film 240 is deposited are the same as those of the manufacturing method of the second embodiment, the description thereof is omitted.

As described above, in the fourth embodiment, the magnetostrictive enhancement layer 434 is provided for producing crystal mismatch strain at the interface with the first pinned magnetic layer 331a to increase magnetostriction of the first pinned magnetic layer 331a, thereby more strongly pinning magnetization of the pinned magnetic layer

331. Also, the magnetostrictive enhancement layer 434 is formed to a thickness of as small as 5 Å to 50 Å, and thus it exhibits no antiferromagnetic characteristic even by a heat treatment. Therefore, when the sensing current flows through

5   the GMR element 330, Joule heat is not increased, and a current loss is not increased. Furthermore, it is possible to comply with narrowing of the shield space.

Although, in the fourth embodiment, the magnetostrictive enhancement layer 434 and the first pinned magnetic layer

10   331a are epitaxially joined with each other, the magnetostrictive enhancement layer 434 and the first pinned magnetic layer 331a may be heteroepitaxially joined with each other. In this case, the crystal structure of each of the magnetostrictive enhancement layer 434 and the first pinned

15   magnetic layer 331a can be appropriately distorted at the interface therebetween (a degree causing no distortion of the atomic arrangements of the fist pinned magnetic layer 331a, the nonmagnetic intermediate layer 331b, and the second pinned magnetic layer 331c).

20   Specifically, the first pinned magnetic layer 331a comprises Co_nFe_m (m ≥ 20 and n + m = 100). In this case, the first pinned magnetic layer 331a has a body-centered cubic structure (bcc), and an equivalent crystal plane represented by {110} plane is preferentially oriented in parallel with

25   the interface with the magnetostrictive enhancement layer 434. Since the atomic arrangement of an equivalent crystal plane represented by {110} plane of a crystal having a body-centered cubic structure is similar to the atomic arrangement

of an equivalent crystal structure represented by {111} plane
of a crystal having a face-centered cubic structure, the
constituent atoms of the magnetostrictive enhancement layer
434 having a face-centered cubic structure can be

5   heteroepitaxially joined to the constituent atoms of the
first pinned magnetic layer 331a having a body-centered cubic
structure.   However, there is a predetermined difference or
more between the nearest neighbor interatomic distance in
{110} plane of the first pinned magnetic layer 331a and the

10   nearest neighbor interatomic distance in {111} plane of the
magnetostrictive enhancement layer 434.   Therefore, the
crystal structures of the first pinned magnetic layer 331a
and the magnetostrictive enhancement layer 434 are
appropriately distorted near the interface therebetween while

15   causing overlap between the constituent atoms of both layers.
The magnetostriction of the first pinned magnetic layer 331a
is increased by the distortion.

As described above, the material used for forming the
first pinned magnetic layer 331a may be Co_nFe_m (m ≥ 20 and n

20   + m = 100) having a body-centered cubic structure or Co or
Co_nFe_m (m ≤ 20 and n + m = 100) having a face-centered cubic
structure.   When Co_nFe_m (m ≥ 20 and n + m = 100) having a
body-centered cubic structure is used, positive
magnetostriction can be more increased than that in the use

25   of Co or Co_nFe_m (m ≤ 20 and n + m = 100) having a face-
centered cubic structure.   When Co or Co_nFe_m (m ≤ 20 and n +
m = 100) having a face-centered cubic structure is used,
coercive force is increased, and magnetization of the first

pinned magnetic layer 331a can be strongly pinned.

Furthermore, the pinned magnetic layer 331a can be formed by using both Co_nFe_m ($m \geq 20$ and $n + m = 100$) having a body-centered cubic structure and Co or Co_nFe_m ($m \leq 20$ and n

5   $+ m = 100$) having a face-centered cubic structure. Specifically, the composition near the interface with the magnetoresistive enhancement layer 434 may comprise Co or Co_nFe_m ($m \leq 20$ and $n + m = 100$), and the composition near the interface with the nonmagnetic intermediate layer 331b may

10 comprise Co_nFe_m ($m \geq 20$ and $n + m = 100$). In this case, the Fe concentration gradually increases from the interface with the magnetoresistive enhancement layer 434 to the nonmagnetic intermediate layer 331b.

The CPP-GMR head of each of the second to fourth

15 embodiments is a type in which the pinned magnetic layer 231 (331) is deposited below the nonmagnetic layer 232 (332).

Next, a type according to fifth to eighth embodiments in which a pinned magnetic layer is disposed above a nonmagnetic layer will be described.

20 Figs. 26 to 28 show a CPP giant magnetoresistive head (CPP-GMR heat) according to the fifth embodiment of the present invention.

The CPP-GMR head of the fifth embodiment is a type in which a pinned magnetic layer is laminated on a nonmagnetic

25 layer, and an antiferromagnetic layer 534 is provided on a first pinned magnetic layer 531a rearwardly extending in the height direction.

Fig. 26 is a partial sectional view showing the

structure of a CPP-GMR head 501, taken along a central line of an element, Fig. 27 is a partial sectional view showing the structure of the CPP-GMR head 501, as viewed from a surface facing a recording medium, and Fig. 28 is a schematic

5   top plan view of a GMR element 530. In Figs. 26 to 28, the functions, materials and thicknesses of layers denoted by the same reference numerals as those in the second embodiment shown in Figs. 6 to 8 are the same as those in the second embodiment.

10   The CPP-GMR head 501 comprises the GMR element 530 exhibiting the GMR effect when a sensing current flows through the lower shield layer 10 and the upper shield layer 50 in the thickness direction. In the GMR element 530, the lamination order of the layers is opposite to that in the GMR

15   element of each of the second to fourth embodiments. Namely, in this embodiment, a free magnetic layer 533, a nonmagnetic layer 532, and a pinned magnetic layer 531 (a second pinned magnetic layer 531c, a nonmagnetic intermediate layer 531b, and a first pinned magnetic layer 531a) are laminated in that

20   order from below. The shapes, thicknesses and materials of the free magnetic layer 533 and the nonmagnetic layer 532 are the same as those of the free magnetic layer 233 and the nonmagnetic layer 232, respectively, in the second embodiment.

Like the pinned magnetic layer 231 of the second

25   embodiment, each of the layers of the pinned magnetic layer 531 comprises a magnetic material having a positive magnetostriction constant, and the end surface of the-pinned magnetic layer 531 is exposed at the surface facing the

recording medium, as shown in Fig. 26. Therefore, the magnetization direction of the pinned magnetic layer 531 is stabilized in a single direction parallel to the height direction by the inverse magnetostrictive effect.

5   In the pinned magnetic layer 531, the first pinned magnetic layer 531a extends beyond the GMR element portion (the free magnetic layer 533, the nonmagnetic layer 532, the second pinned magnetic layer 531c and the nonmagnetic intermediate layer 531b) in the track width direction and in

10   the height direction. Namely, the height dimension h2 of the first pinned magnetic layer 531a is larger than the height dimension h1 of the GMR element 530, and the track width-direction dimension Tw' is larger than the track width dimension Tw of the GMR element 530. Also, the height

15   dimension h2 of the first pinned magnetic layer 531a is larger than the track width-direction dimension Tw' to produce shape anisotropy in the first pinned magnetic layer 531a in parallel with the height direction. Therefore, magnetization of the first pinned magnetic layer 531a is

20   stabilized by the shape anisotropy in a direction parallel to the height direction.

      Also, an upper nonmagnetic metal film 540 is formed on the first pinned magnetic layer 531a and above the GMR element 530, and the antiferromagnetic layer 534 is formed in

25   the rear of the GMR element 530 and the upper nonmagnetic metal film 540 in the height direction. In the first pinned magnetic layer 531a, a portion on which the antiferromagnetic layer 534 is formed has a smaller thickness than that of a

portion on which the upper nonmagnetic metal film 540 is formed.

The material and thickness of the antiferromagnetic layer 534 are the same as those of the antiferromagnetic layer 234 in the second embodiment, and the antiferromagnetic layer 534 is in contact with the upper surface of a rear portion of the first pinned magnetic layer 531a which extends in the height direction beyond the GMR element 530. The antiferromagnetic layer 534 produces an exchange coupling magnetic field at the interface with the first pinned magnetic layer 531a, so that the magnetization direction of the first pinned magnetic layer 531a is pinned in antiparallel to the height direction by the exchange coupling magnetic field. The first and second pinned magnetic layers 531a and 531c have antiparallel magnetization directions due to a RKKY interaction through the nonmagnetic intermediate layer 531b. Therefore, magnetization of the second pinned magnetic layer 531c is pinned in the height direction. In this embodiment, the magnetic moment per unit area of the first pinned magnetic layer 531a is larger than that of the second pinned magnetic layer 531c, and thus the magnetization direction of the whole pinned magnetic layer 531 is the same as that of the first pinned magnetic layer 531a. The thicknesses of the second pinned magnetic layer 531c and the nonmagnetic intermediate layer 531b are the same as those of the second pinned magnetic layer 231c and the nonmagnetic intermediate layer 231b, respectively, in the second embodiment.

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The lengths of the upper nonmagnetic metal film 540 in
the track width direction and in the height direction are
larger than those of the GMR element 530 (the free magnetic
layer 533, the nonmagnetic layer 532, the second pinned

5   magnetic layer 531c and the nonmagnetic intermediate layer
531b). The upper nonmagnetic metal film 540 functions as an
electrode together with the upper shied layer 50. The upper
nonmagnetic metal film 540 can be formed to the same
thickness as that of the upper nonmagnetic metal film 240 of

10 the second embodiment by using the same material as in the
second embodiment.

Furthermore, a lower nonmagnetic metal film 520 is
formed directly below the free magnetic layer 533 to have a
larger length than that of the free magnetic layer 533 in the

15 height direction and substantially the same length as the
free magnetic layer 533 in the track width direction. The
lower nonmagnetic metal film 520 functions as an electrode
together with the lower shield layer 10 and functions as a
seed layer for regularly forming the layers constituting the

20 GMR element 530. The material and thickness of the lower
nonmagnetic metal film 520 can be set to the same as those of
the lower nonmagnetic metal film 220 in the second embodiment.
In this embodiment, the lower nonmagnetic metal film 520 is
formed in a Ta/Cr two-layer structure.

25 Furthermore, a space between the rear portion of the
first pinned magnetic layer 531a and the lower nonmagnetic
metal film 520 and in the rear of the layers ranging from the
free magnetic layer 533 to the nonmagnetic intermediate layer

531b in the height direction is filled with a backfill gap layer 570. The backfill gap layer 570 comprises an insulating material such as Al_2O_3 or SiO_2, for suppressing a shut of the sensing current.

5   Next, a method for manufacturing the CPP-GMR head 501 shown in Figs. 26 to 28 according to an embodiment of the present invention will be described below. Since the material and thickness of each of the layers are the same as those in the completed CPP-GMR head 501, the description

10   thereof is omitted.

First, the lower nonmagnetic metal film 520, the free magnetic layer 533, the nonmagnetic layer 532, the second pinned magnetic layer 531c, and the nonmagnetic intermediate layer 531b are continuously deposited on the lower shield

15   layer 10 in that order from below. These layers are deposited by sputtering. When the nonmagnetic intermediate layer 531b comprises an oxidizable magnetic material, an antioxidative layer is preferably formed to a thickness of as small as 5 Å to 10 Å on the nonmagnetic intermediate layer

20   531b, for preventing surface oxidation of the nonmagnetic intermediate layer 531b.

Next, a resist layer is formed on the nonmagnetic intermediate layer 531b, for determining the track width dimension Tw of the GMR element 530 to be formed.

25   After the resist layer is formed, portions of the layers ranging from the nonmagnetic intermediate layer 531b to the lower nonmagnetic metal film 520, which are not covered with the resist layer, are removed by, for example, ion milling to

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expose the lower shield layer 10 in the removed portion. In this step, the layers ranging from the nonmagnetic metal film 520 to the nonmagnetic intermediate layer 531b are left on the lower shield layer at substantially the center thereof in

5   the track width direction.

Then, the first insulating layers 61, the bias underlying layers 62, the hard bias layers 63 and the second insulating layers 64 are continuously deposited on both sides of the layers in the track width direction with the resist

10 layer left on the nonmagnetic intermediate layer 531b, the layers ranging from the lower nonmagnetic metal film 520 to the nonmagnetic intermediate layer 531b. These layers are deposited by sputtering. In sputtering deposition, the angle of sputtered particles is preferably about 90 degrees with

15 the lower nonmagnetic metal film 520. After sputtering deposition, the resist layer is removed by liftoff.

After the resist layer is removed, a resist layer is formed on the nonmagnetic intermediate layer 531b, for determining the height dimension h1 of the GMR element 530 to

20 be formed, and portions of the nonmagnetic intermediate layer 531b, the second pinned magnetic layer 531c, the nonmagnetic layer 532 and the free magnetic layer 533, which are not covered with the resist layer, are removed by, for example, ion milling. In this step, the nonmagnetic intermediate

25 layer 531b, the second pinned magnetic layer 531c, the nonmagnetic layer 532 and the free magnetic layer 533 have a height dimension equal to the height dimension h1 of the GMR element 530.

The step of determining the track width dimension Tw of the GMR element 530 and the step of determining the height dimension h1 may be reversed.

Then, with the resist layer left on the nonmagnetic
5   intermediate layer 531b, the backfill gap layer 570 is deposited in the rear of the nonmagnetic intermediate layer 531b, the second pinned magnetic layer 531c, the nonmagnetic layer 532, and the free magnetic layer 533 in the height direction. After the backfill gap layer 570 is deposited,
10 the resist layer is removed by liftoff.

After the resist layer is removed, a new resist layer having an aperture for forming the first pinned magnetic layer 531a is formed on the nonmagnetic intermediate layer 531b. Then, the surface of the nonmagnetic intermediate
15 layer 531b exposed from the resist layer is cleaned by low-energy ion beam etching or plasma irradiation, and then the first pinned magnetic layer 531a and the upper nonmagnetic metal film 540 are continuously deposited. After deposition, the resist layer is removed by liftoff.

20   The term "low-energy ion beam etching" means ion milling using an ion beam with a beam voltage (acceleration voltage) of less than 1000 V. For example, a beam voltage of 100 V to 500 V is used. In this embodiment, an argon (Ar) ion beam with a low beam voltage of 200 V is used. This definition of
25 "low-energy ion beam etching" applies to the description below.

Then, a new resist layer having an aperture for forming the antiferromagnetic layer 534 is formed on the upper

nonmagnetic metal film 540. Then, portions of the upper

nonmagnetic metal film 540 and a portion of the first pinned

magnetic layer 531a, which are not covered with the resist

layer, are removed by, for example, and the antiferromagnetic

5   layer 534 is deposited in the removed portion. After the

deposition of the antiferromagnetic layer 534, the resist

layer is removed by liftoff.

Like in the second embodiment, annealing is then

performed in a magnetic field in the height direction, and

10   the upper shield layer 50 is formed over the upper

nonmagnetic metal film 540 and the antiferromagnetic layer

534. The CPP-GMR head 501 shown in Figs. 26 to 28 is

completed by the above-described steps.

As described above, in the fifth embodiment, the

15   antiferromagnetic layer 534 is provided in contact with the

upper surface of the rear portion of the first pinned

magnetic layer 531a which extends in the height direction

beyond the GMR element portion (ranging from the free

magnetic layer 533 to the nonmagnetic intermediate layer

20   531b), for producing an exchange coupling magnetic field at

the interface with the first pinned magnetic layer 531a.

Therefore, like in the second to fourth embodiments, a wide

contact area (an area where an exchange coupling magnetic

field occurs) can be secured between the first pinned

25   magnetic layer 531a and the antiferromagnetic layer 534 to

stably and strongly pin magnetization of the pinned magnetic

layer 531. The contact area between the first pinned

magnetic layer 531a and the antiferromagnetic layer 534 is

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larger that in the case in which the antiferromagnetic layer

is in contact with the rear end surface of any one of the

first pinned magnetic layer and the second pinned magnetic

layer like in the first embodiment. In this embodiment, the

5   contact area between the first pinned magnetic layer 531a and

the antiferromagnetic layer 534 is 500 times or more as large

as that between the first pinned magnetic layer 33c and the

antiferromagnetic layer 34 in the first embodiment.

Like in the second to fourth embodiments, in the fifth

10   embodiment, magnetization pinning of the first and second

pinned magnetic layers 531a and 531c is also strengthened by

uniaxial anisotropy due to the inverse magnetostrictive

effect, shape anisotropy, and the seed effect of the lower

nonmagnetic metal film 520. In this way, when magnetization

15   of each of the first pinned magnetic layer 531a and the

second pinned magnetic layer 531c is strongly pinned,

magnetization of the pinned magnetic layer 531 is not

fluctuated by the generated sensing current magnetic field

even if the direction of the sensing current magnetic field

20   is not the same as that of the synthetic magnetic moment of

the first and second pinned magnetic layers 531a and 531c.

Therefore, the sensing current density can be increased to

increase output.

Like in the second to fourth embodiments, in the fifth

25   embodiment, even when the sensing current is passed through

the GMR element 530, the antiferromagnetic layer 534 does not

generate heat to suppress an increase in the element

temperature, thereby improving reliability. Also, the shield

distance R-GL at the surface facing the recording medium can be decreased in comparison to the conventional head shown in Fig. 55, thereby improving resolution.

Figs. 29 to 35 show a CPP giant magnetoresistive head (CPP-GMR heat) according to the sixth embodiment of the present invention.

Like in the fifth embodiment, in the sixth embodiment, an antiferromagnetic layer 534 is provided on a first pinned magnetic layer 531a rearwardly extending in the height direction. However, the sixth embodiment is different from the fifth embodiment in the production method.

Fig. 29 is a partial sectional view showing the structure of a CPP-GMR head 601, taken along a central line of an element, Fig. 30 is a partial sectional view showing the structure of the CPP-GMR head 601, as viewed from a surface facing a recording medium, and Fig. 31 is a schematic top plan view of a GMR element 530. In Figs. 29 to 31, the functions, materials and thicknesses of layers denoted by the same reference numerals as those in the fifth embodiment shown in Figs. 26 to 28 are the same as those in the fifth embodiment.

In the CPP-GMR head 601, an upper nonmagnetic metal film 640 comprises a first nonmagnetic metal film 641 formed to cover the upper surface of the antiferromagnetic layer 534, and a second nonmagnetic metal film 642 formed over the first nonmagnetic metal film 641 and the first pinned magnetic layer 531a. The first nonmagnetic metal film 641 functions as a stopper in RIE (reactive ion etching) performed in the

manufacturing process, and comprises Cr. A metal mask layer 650 may be interposed between the first nonmagnetic metal film 641 and the second nonmagnetic metal film 642. In this embodiment, differences in shape and structure of the upper nonmagnetic metal film 640 from the upper nonmagnetic metal film 540 of the fifth embodiment are caused by a difference between the production methods, and the effect of the upper nonmagnetic metal film is the same as in the fifth embodiment.

A method for manufacturing the CPP-GMR head 601 shown in Figs. 29 to 31 according to an embodiment of the present invention will be described below with reference to Figs. 32 to 35. Since the material and thickness of each of the layers are the same as those in the completed CPP-GMR head 601, the description thereof is omitted.

First, the lower nonmagnetic metal film 520, the free magnetic layer 533, the nonmagnetic layer 532, the second pinned magnetic layer 531c, and the nonmagnetic intermediate layer 531b are continuously deposited on the lower shield layer 10 in that order from below by the same method as in the fifth embodiment.

Next, a resist layer is formed on the nonmagnetic intermediate layer 531b, for determining the height dimension h1 of the GMR element 530 to be formed.

After the resist layer is formed, portions of the layers ranging from the nonmagnetic intermediate layer 531b to the lower nonmagnetic metal film 520, which are not covered with the resist layer, are removed by, for example, ion milling, and a backfill gap layer 570 is formed in the removed portion.

Then, the resist layer is removed by liftoff.

Then, the surfaces of the nonmagnetic intermediate layer 531b and the backfill gap layer 570 are cleaned by low-energy ion milling or plasma irradiation. After cleaning, as shown in Fig. 32, the first pinned magnetic layer 531a, the antiferromagnetic layer 534 and the first nonmagnetic metal film 641 are continuously deposited over the nonmagnetic intermediate layer 531b and the backfill gap layer 570. The first nonmagnetic metal film 641 functions as a stopper in a subsequent RIE step. The first nonmagnetic metal film 641 is formed in a two-layer structure comprising a Cr film 641a and a Ta film 641b.

Then, a resist layer having an aperture for forming the antiferromagnetic layer 534 is formed on the first nonmagnetic metal film 641, and the metal mask layer 650 is formed. Then, unnecessary portions of the metal mask layer 650 and the resist layer are removed by liftoff. As a result, as shown in Fig. 33, the metal mask 650 is formed in a region where the antiferromagnetic layer 534 is formed. The metal mask layer 650 can be formed by using, for example, Cr.

After the metal mask layer 650 is formed, the exposed portion of the Ta film 641b is removed by RIE, as shown in Fig. 34. As an etching gas, CF_4, C_3F_8, a mixed gas of Ar and CF_4, or a mixed gas of Ar and C_3F_8 is used. RIE is stopped when the Cr film 641a of the first nonmagnetic metal film 641 is exposed. In the RIE steps, the Ta film 641b of the first nonmagnetic metal film 641 is left only below the metal mask layer 650.

Then, as shown in Fig. 35, unnecessary portions of the antiferromagnetic layer 534 are removed by ion milling using, as a mask, the metal mask layer 650 present in the region where the antiferromagnetic layer 534 is formed, and the Ta

5 film 641b of the first nonmagnetic metal film 641. The ion milling step is stopped when the upper surface of the first pinned magnetic layer 531a is exposed or when a part of the first pinned magnetic layer 531a is removed. In this step, the metal mask layer 650 used s the mask is also removed, and

10 thus the Ta film 641b and the Cr film 641a of the first nonmagnetic metal film 641, and a part of the metal mask layer 650 are left on the upper surface of the antiferromagnetic layer 534. The metal mask layer 650 and the Ta film 641b may be completely removed to leave only the

15 Cr film 641a on the antiferromagnetic layer 534. In this embodiment, the first pinned magnetic layer 641, and a part of the metal mask layer 650 are left on the upper surface of the antiferromagnetic layer 534.

After ion milling, the second nonmagnetic metal film 642

20 is deposited on the exposed portion of the first pinned magnetic layer and the metal mask layer 650 or on the first nonmagnetic metal film 641 to cover the antiferromagnetic layer 534. The second nonmagnetic metal film 642 comprises the same magnetic material as that for forming the upper

25 nonmagnetic metal film 540 of the fifth embodiment.

Then, annealing is then performed in a magnetic field in antiparallel to the height direction to produce an exchange coupling magnetic field between the antiferromagnetic layer

534 and the first pinned magnetic layer 531a. For example,
the annealing temperature is about 270°C, and the magnitude
of the applied magnetic field is about 800 kA/m. In the
annealing in the magnetic field, the magnetization direction

5   of the first pinned magnetic layer 531a is pinned in
antiparallel to the height direction, and the magnetization
direction of the second pinned magnetic layer 531c is pinned
in the height direction. In Fig. 29, the magnetization
direction of each of the first and second pinned magnetic

10   layers 531a and 531c is shown by an arrow.

The magnetic field annealing may be performed after the
track width dimension of the GMR element 530 to be formed is
determined.

After annealing, a resist layer is formed on the second

15   upper nonmagnetic metal film 642, for determining the track
width dimension Tw of the GMR element 530 to be formed, and
portions of the second upper nonmagnetic metal film 642, the
first pinned magnetic layer 531a, the nonmagnetic
intermediate layer 531b, the second pinned magnetic layer

20   531c, the nonmagnetic layer 532, the free magnetic layer 533
and the lower nonmagnetic metal film 520, which are not
covered with the resist layer, are removed by ion milling.
In this step, the lower nonmagnetic metal film 520, the GMR
element 530 ranging from the first pinned magnetic layer 331a

25   to the free magnetic layer 333, and the second upper
nonmagnetic metal film 642 are left on the lower shield layer
101 at the substantially center thereof in the track width
direction. Since the substances removed by ion milling

partially re-adhere to both sides of the GMR element 530, the re-adhering substances are preferably removed by milling again.

Then, in the state in which the resist layer remains, the first insulating layers 61, the bias underlying layers 62, the hard bias layers 63, and the second insulating layers 64 are continuously deposited on both sides of the GMR element 530. These layers are deposited by sputtering. In sputtering deposition, the angle of sputtered particles is preferably about 90 degrees with the lower shield layer 10. After sputtering deposition, the resist layer is removed by liftoff.

After the resist layer is removed, as a pre-treatment for forming the upper shield layer, the upper surfaces of the second upper nonmagnetic metal film 642 and the second insulating layers 64 are planarized by, for example, CMP or ion milling, and the upper shield layer 50 is deposited on the planarized surfaces of the second upper nonmagnetic metal film 642 and the second insulating layers 64. The CPP-GMR head 601 shown in Figs. 29 to 31 is completed by the above-described steps.

In the sixth embodiment, the same effect as in the fifth embodiment can be obtained.

Figs. 36 to 38 show a CPP giant magnetoresistive head (CPP-GMR heat) according to the seventh embodiment of the present invention.

The seventh embodiment is different from the fifth and sixth embodiments in that not only a first pinned magnetic

layer but also the whole of a pinned magnetic layer (the first pinned magnetic layer, a nonmagnetic intermediate layer, and a second pinned magnetic layer) extends beyond the GMR element portion (a free magnetic layer and a nonmagnetic

5   layer) in the track width direction and in the height direction. The seventh embodiment is the same as the fifth and sixth embodiments in the point that an antiferromagnetic layer is provided in contact with the upper surface of a rear portion of the first pinned magnetic layer extending in the

10   height direction.

Fig. 36 is a partial sectional view showing the structure of a CPP-GMR head 701, taken along a central line of the element, Fig. 37 is a partial sectional view showing the structure of the CPP-GMR head 701, as viewed from a

15   surface facing a recording medium, and Fig. 38 is a schematic top plan view of the GMR element. In Figs. 36 to 38, the functions, materials and thicknesses of layers denoted by the same reference numerals as those in the fifth embodiment shown in Figs. 26 to 28 are the same as those in the fifth

20   embodiment.

In the GMR head 730, a free magnetic layer 733, a nonmagnetic layer 732, a second pinned magnetic layer 731c, a nonmagnetic intermediate layer 731b and a first pinned magnetic layer 731a are laminated in that order from below.

25   The free magnetic layer 733, the nonmagnetic layer 732, the second pinned magnetic layer 731c, the nonmagnetic intermediate layer 731b and the first pinned magnetic layer 731a correspond to the free magnetic layer 533, the

nonmagnetic layer 532, the second pinned magnetic layer 531c,
the nonmagnetic intermediate layer 531b and the first pinned
magnetic layer 531a, respectively, in the fifth embodiment.
The materials and thicknesses of these layers are the same as
5   those in the fifth embodiment.

As described above, the second pinned magnetic layer
731c, the nonmagnetic intermediate layer 731b and the first
pinned magnetic layer 731a extend beyond the GMR element
portion (the free magnetic layer 733 and the nonmagnetic
10   layer 732) in the track width direction and in the height
direction. Therefore, a coupling magnetic field is produced
between the first pinned magnetic layer 731a and the second
pinned magnetic layer 731c due to a RKKY interaction through
the nonmagnetic intermediate layer 731b even in a region
15   outside the GMR element portion. Thus, magnetization of the
second pinned magnetic layer 731c can be strongly pinned to
more strongly pin the pinned magnetic layer 731, as compared
with the fifth embodiment in which only the first pinned
magnetic layer 531a extends.

20   Like in the fifth embodiment, an antiferromagnetic layer
734 produces an exchange coupling magnetic field at the
interface with the first pinned magnetic layer 731a, and
magnetization of the first pinned magnetic layer 731a is
pinned in antiparallel to the height direction by the
25   exchange coupling magnetic field. Magnetization of the
second pinned magnetic layer 731c is pinned in the height
direction because the magnetization is antiparallel to
magnetization of the first pinned magnetic layer 731a due to

the RKKY interaction through the nonmagnetic intermediate layer 731b.

The second pinned magnetic layer 731c, the nonmagnetic intermediate layer 731b and the first pinned magnetic layer
5 731a have a height dimension h2 larger than the track width dimension Tw', and thus magnetization is also stabilized by shape anisotropy in a direction parallel to the height direction.

The CPP-GMR head 701 can be manufactured by the same
10 manufacturing method as that of the fifth embodiment. Specifically, in the first step of depositing some of the layers of the GMR element on the lower shield layer 10, the layers up to the nonmagnetic layer 732 are deposited. Next, the steps from the step of determining the track width
15 dimension of the GMR element 730 to be formed to the step of determining the height dimension h1 of the GMR element 730 to be formed are successively performed in the same method as in the fifth embodiment. In the step of depositing the other layers of the GMR element 730, the second pinned magnetic
20 layer 731c, the nonmagnetic intermediate layer 731b and the first pinned magnetic layer 731a are continuously deposited on the nonmagnetic layer 732, a backfill gap layer 770, and the second insulating layers 640. The steps after the first pinned magnetic layer 731a is deposited are the same as in
25 the fifth embodiment.

As described above, in the seventh embodiment, not only the first pinned magnetic layer 731a but also all of the first pinned magnetic layer 731a, the nonmagnetic

intermediate layer 731b and the second pinned magnetic layer 731c extend beyond the GMR element portion (the free magnetic layer 733 and the nonmagnetic layer 732) in the track width direction and in the height direction. Therefore,

5   magnetization coupling between the first pinned magnetic layer 731a and the second pinned magnetic layer 731c due to the RKKY interaction is strengthened to more strongly pin magnetization of the pinned magnetic layer 731, as compared with the fifth and sixth embodiments.

10   Also, in the seventh embodiment, the second pinned magnetic layer 731c, the nonmagnetic intermediate layer 731b and the first pinned magnetic layer 731a are continuously deposited to prevent contamination of the laminate interfaces with impurities and air. Therefore, deterioration of a

15   coupling magnetic field produced between the first pinned magnetic layer 731a and the second pinned magnetic layer 731c due to the RKKY interaction can be prevented to more strongly pin magnetization of the pinned magnetic layer 731.

Figs. 39 to 41 show a CPP giant magnetoresistive head

20   (CPP-GMR heat) according to the eighth embodiment of the present invention.

Like in the seventh embodiment, in the eighth embodiment, the whole of a pinned magnetic layer extends beyond a GMR element portion in the track width direction and in the

25   height direction, and an antiferromagnetic layer is provided in contact with the upper surface of a rear portion of the first pinned magnetic layer extending in the height direction. However, the production method of the eighth embodiment is

different from the seventh embodiment.

Fig. 39 is a partial sectional view showing the structure of a CPP-GMR head 801, taken along a central line of the element, Fig. 40 is a partial sectional view showing

5 the structure of the CPP-GMR head 801, as viewed from a surface facing a recording medium, and Fig. 41 is a schematic top plan view of the GMR element. In Figs. 39 to 41, the functions, materials and thicknesses of layers denoted by the same reference numerals as those in the seventh embodiment

10 shown in Figs. 36 to 38 are the same as those in the fifth embodiment.

In the CPP-GMR head 801, an upper nonmagnetic metal film 840 comprises a first nonmagnetic metal film 841 formed to cover the upper surface of the antiferromagnetic layer 734,

15 and a second nonmagnetic metal film 842 formed over the first nonmagnetic metal film 841 and the first pinned magnetic layer 731a. The first nonmagnetic metal film 841 functions as a stopper in RIE (reactive ion etching) performed in the manufacturing process, and comprises Cr. Like in the sixth

20 embodiment, a metal mask layer may be interposed between the first nonmagnetic metal film 841 and the second nonmagnetic metal film 842. The first nonmagnetic metal film 841 and the second nonmagnetic metal film 842 correspond to the first nonmagnetic metal film 641 and the second nonmagnetic metal

25 film 642, respectively, in the sixth embodiment. The materials and thicknesses of the first nonmagnetic metal film 841 and the second nonmagnetic metal film 842 are the same as those in the sixth embodiment. In this embodiment,

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differences in shape and structure of the upper nonmagnetic metal film 840 from the upper nonmagnetic metal film 740 of the seventh embodiment are caused by a difference between the production methods, and the effect of the upper nonmagnetic

5   metal film is the same as in the seventh embodiment.

The CPP-GMR head 801 can be manufactured by the same manufacturing method as that of the sixth embodiment. Specifically, in the first step of depositing some of the layers of the GMR element on the lower shield layer 10, the

10 layers up to the nonmagnetic layer 732 are continuously deposited. Next, the steps from the step of determining the height dimension h1 of the GMR element 730 to be formed to the step of cleaning the surfaces by low-energy ion beam etching are successively performed by the same method as in

15 the sixth embodiment. In the step of depositing the other layers of the GMR element, the second pinned magnetic layer 731c, the nonmagnetic intermediate layer 731b and the first pinned magnetic layer 731a are continuously deposited on the nonmagnetic layer 732 and a backfill gap layer 770. The

20 steps after the deposition of the first pinned magnetic layer 731a are the same as in the sixth embodiment.

In the eighth embodiment, the same effect as in the seventh embodiment can be obtained.

Fig. 42 shows a CPP giant magnetoresistive head (CPP-GMR

25 head) according to a ninth embodiment of the present invention. In a CPP-GMR head 901 of this embodiment, the antiferromagnetic layer 234 and the first backfill gap layer 271 of the CPP-GMR head 201 of the second embodiment are

replaced by an insulating antiferromagnetic layer 234'. The
insulating antiferromagnetic layer 234' comprises, for
example, Ni-O or α-Fe$_2$O$_3$. Since no sensing current flows
through the insulating antiferromagnetic layer 234', a loss

5   of the sensing current can be suppressed to improve output.
The ninth embodiment is the same as the second embodiment
except that the insulating antiferromagnetic layer 234' is
provided, and the same components as in the second embodiment
shown in Fig. 6 are denoted by the same reference numerals as

10   in the second embodiment.

The CPP-GMR head 901 can be manufactured by the same
manufacturing method as that of the second embodiment except
that in forming the antiferromagnetic layer 234 and the first
backfill gap layer 271, the insulating antiferromagnetic

15   layer 234' comprising Ni-O or α-Fe$_2$O$_3$ is formed in place of
the antiferromagnetic layer 234 and the first backfill gap
layer 271.

Fig. 43 shows a CPP giant magnetoresistive head (CPP-GMR
head) according to a tenth embodiment of the present

20   invention. In a CPP-GMR head 1001 of this embodiment, the
antiferromagnetic layer 234 and the first backfill gap layer
271 of the CPP-GMR head 201 of the second embodiment are
replaced by an antiferromagnetic metal layer 236 in contact
with the upper surface of the second pinned magnetic layer

25   231c and an insulating antiferromagnetic layer 237 laminated
on the antiferromagnetic metal layer 236. In this way, when
the antiferromagnetic metal layer 236 and the insulating
antiferromagnetic layer 237 are laminated, adhesion between

the second pinned magnetic layer 231c and the insulating

antiferromagnetic layer 237 is improved through the

antiferromagnetic metal layer 236 to obtain a great exchange

coupling magnetic field. Also, a loss of the sensing current

5   can be suppressed by the insulating antiferromagnetic layer

237 to improve output. The insulating antiferromagnetic

layer 237 comprises Ni-O or α-Fe$_2$O$_3$, and the

antiferromagnetic metal layer 236 comprises the same

antiferromagnetic material as the antiferromagnetic layer 34,

10 for example, Pt-Mn, Ir-Mn, or the like.

The CPP-GMR head 1001 can be manufactured by the same

manufacturing method as that of the second embodiment except

that in forming the antiferromagnetic layer 234 and the first

backfill gap layer 271, the antiferromagnetic metal layer 236

15 and the insulating antiferromagnetic layer 237 are laminated

in place of the antiferromagnetic layer 234 and the first

backfill gap layer 271.

Figs. 44 to 48 show a CPP giant magnetoresistive head

(CPP-GMR head) according to an eleventh embodiment of the

20 present invention.

In the eleventh embodiment, in the CPP-GMR head 701 of

the seventh embodiment, the antiferromagnetic layer 734 is

not provided, and an insulating antiferromagnetic layer 1134

is provided in contact with the lower surface of a second

25 pinned magnetic layer in place of the backfill gap layer 770.

Fig. 44 is a partial sectional view showing the

structure of the CPP-GMR head 1101, taken along a central

line of an element, Fig. 45 is a partial sectional view

showing the structure of the CPP-GMR head 1101, as viewed from a surface facing a recording medium, and Fig. 46 is a schematic top plan view of a GMR element. In Figs. 44 to 46, the functions, materials and thicknesses of layers denoted by

5 the same reference numerals as those in the seventh embodiment shown in Figs. 36 to 38 are the same as those in the seventh embodiment.

The CPP-GMR head 1101 comprises a GMR element 1130 exhibiting the GMR effect when a sensing current is passed

10 through an upper shield layer 50 and a lower shield layer 10 in the thickness direction. In the GMR element 1130, a lower nonmagnetic metal film 520, a free magnetic layer 1133, a nonmagnetic layer 1132, a pinned magnetic layer 1131 (a second pinned magnetic layer 1131c, a nonmagnetic

15 intermediate layer 1131b and a first pinned magnetic layer 1131a), an upper nonmagnetic metal film 540 are laminated in that order from below. The shapes, thicknesses and materials of the nonmagnetic layer 1132 and the free magnetic layer 1133 are the same as those of the nonmagnetic layer 732 and

20 the free magnetic layer 733, respectively, in the seventh embodiment. In the lower nonmagnetic metal film 520, a portion in the GMR element 1130 has a larger thickness, and a portion outside the element has a smaller thickness. The upper nonmagnetic metal film 540 is formed in substantially

25 the same area as the pinned magnetic layer 1131 to cover the upper surface of the pinned magnetic layer 1131.

The pinned magnetic layer 1131 extends to the rear of the nonmagnetic layer 1132 and the free magnetic layer 1133

in the height direction, and is in contact with the rear
portion of the insulating antiferromagnetic layer 1134 in the
height direction. In this embodiment, in consideration of
alignment between the nonmagnetic layer 1132 and the free
5   magnetic layer 1133, the pinned magnetic layer 1131 also
extends in the track width direction beyond the nonmagnetic
layer 1132 and the free magnetic layer 1133. Namely, the
track width dimension RTw and the height dimension h2 of the
pinned magnetic layer 1131 are larger than the track width
10   dimension Tw and the height dimension h1 of the GMR element
1131. Also, the length of the pinned magnetic layer 1131 in
the height direction is larger than that in the track width
direction, and thus the magnetization direction of the pinned
magnetic layer 1131 is stabilized by shape anisotropy in a
15   direction parallel to the height direction. The
magnetization direction of the second pinned magnetic layer
1131c of the pinned magnetic layer 1131 is pinned in
antiparallel to the height direction by an exchange coupling
magnetic field produced at the interface with the insulating
20   antiferromagnetic layer 1134. The second pinned magnetic
layer 1131c and the first pinned magnetic layer 1131a have
antiparallel magnetizations due to the RKKY interaction
through the nonmagnetic intermediate layer 1131b. Therefore,
magnetization of the first pinned magnetic layer 1131a is
25   pinned in the height direction. In this embodiment, the
magnetic moment per unit area (saturation magnetization × Ms
thickness t) of the first pinned magnetic layer 1131a is
larger than that of the second pinned magnetic layer 1131c,

and thus the magnetization direction of the whole pinned magnetic layer 1131 is the same as that of the first pinned magnetic layer 1131a. In Fig. 44, the magnetization direction of the first pinned magnetic layer 1131a is shown by a bold arrow, and the magnetization direction of the second pinned magnetic layer 1131c is shown by a thin arrow.

The insulating antiferromagnetic layer 1134 comprises, for example, Ni-O or α-Fe_2O_3. Since no sensing current flows through the insulating antiferromagnetic layer 1134, the sensing current flowing through the GMR element 1130 does not flow into the insulating antiferromagnetic layer 1134 even when the insulating antiferromagnetic layer 1134 is provided in the rear of the nonmagnetic layer 1132 and the free magnetic layer 1133 and in contact with the lower surface of the second pinned magnetic layer 1131c. Also, a loss of the sensing current is not increased, and the heat generation from the insulating antiferromagnetic layer 1134 can be avoided to suppress the generation of Joule heat.

Next, a method for manufacturing the CPP-GMR head 1101 shown in Figs. 44 to 46 according to an embodiment of the present invention will be described below with reference to Figs. 47 and 48. Figs. 47 and 48B are partial sectional views showing a step for manufacturing the CPP-GMR head 1101, taken along a central line of the element in parallel with the height direction, and Fig. 48A is a partial sectional view showing the same step, as viewed from a surface facing a recording medium. The material and thickness of each layer are the same as those of the completed CPP-GMR head 1101.

First, the lower shield layer 10, the lower nonmagnetic metal film 520, the free magnetic layer 1133, and the nonmagnetic layer 1132 are continuously deposited in a solid form in that order from below in vacuum. Next, a liftoff

5 resist layer is formed on the nonmagnetic layer 1132, for determining the track width dimension Tw of the GMR element 1130 to be formed. After the resist layer is formed, potions of the nonmagnetic layer 1132, the free magnetic layer 1133 and a portion of the lower nonmagnetic metal film 520, which

10 are not covered with the resist layer, are removed by ion milling. In this step, the lower nonmagnetic metal film 520 has a central portion having a larger thickness than that of both sides in the track width direction, and the free magnetic layer 1133 and the nonmagnetic layer 1132 are left

15 in a substantially trapezoidal shape on the central portion. The dimensions of the free magnetic layer 1133 and the nonmagnetic layer 1132 in the track width direction are equal to the track width dimension Tw of the GMR element 1130. Since the substances removed by ion milling partially re-

20 adhere to both sides of the lower nonmagnetic metal film 520, the free magnetic layer 1133 and the nonmagnetic layer 1132, the re-adhering substances are preferably removed by milling again.

Then, in the state in which the resist layer remains,

25 the first insulating layers 61, the bias underlying layers 62, the hard bias layers 63, and the second insulating layers 64 are continuously deposited by sputtering on both sides of the lower nonmagnetic metal film 520. In sputtering deposition,

the angle of sputtered particles is preferably about 90 degrees with the lower nonmagnetic metal film 520. After sputtering deposition, the resist layer is removed by liftoff.

Then, as shown in Fig. 47, a resist layer R2 is formed on the nonmagnetic layer 1132, for determining the height dimension h1 of the GMR element 1130 to be formed. Then, portions of the nonmagnetic layer 1132, the free magnetic layer 1133, and a portion of the lower nonmagnetic metal film 520, which are not covered with the resist layer R2, are removed by ion milling, for example, and the insulating antiferromagnetic layer 1134 is formed in the removed portion. In this ion milling step, the nonmagnetic layer 1132 and the free magnetic layer 1133 are left only in the element portion used as the GMR element 1130. The rear end surfaces of the nonmagnetic layer 1132 and the free magnetic layer 1133 in the height direction are smoothly continued. After the formation of the insulating antiferromagnetic layer 1134, the resist layer R2 is removed.

Then, the second pinned magnetic layer 1131c, the nonmagnetic intermediate layer 1131b, the first pinned magnetic layer 1131a, and the upper nonmagnetic metal film 540 are continuously deposited in turn on the insulating antiferromagnetic layer 1134, the nonmagnetic layer 1132 and the second insulating layer 62. As shown in Fig. 48, a resist layer R3 is then formed on the upper nonmagnetic metal film 540, for determining the track width dimension RTw of the pinned magnetic layer 1131, and portions of the cap layer 1136, the first pinned magnetic layer 1131a, the nonmagnetic

intermediate layer 1131b and the second pinned magnetic layer 1131c, which are not covered with the resist layer R3, are removed by, for example, ion milling. Then, the resist layer R3 is removed. In this step, the pinned magnetic layer 1131

5   (the second pinned magnetic layer 1131c, the nonmagnetic intermediate layer 1131b, and the first pinned magnetic layer 1131a) and the upper nonmagnetic metal film 540, which have larger dimensions than those of the nonmagnetic layer 1132 in the track width direction and in he height direction, are

10 left on the nonmagnetic layer 1132 to form the GMR element 1130. The second insulating layers 64 are exposed on both sides of the pinned magnetic layer 1131 and the upper nonmagnetic metal film 540 in the track width direction. In this embodiment, in order to achieve alignment between the

15 free magnetic layer 1133, the nonmagnetic layer 1132 and the pinned magnetic layer 1131, the dimension RTw of the pinned magnetic layer 1131 in the track width direction is set to be longer than the track width dimension Tw of the GMR element 1130.

20   Then, annealing is performed in a magnetic field in the height direction to produce an exchange coupling magnetic field at the interface between the insulating antiferromagnetic layer 1134 and the second pinned magnetic layer 1131c. For example, the annealing temperature is about

25 270° C, and the magnitude of the applied magnetic field is about 800 kA/m. In the annealing in the magnetic field, the magnetization direction of the second pinned magnetic layer 1131c is pinned in antiparallel to the height direction, and

the magnetization direction of the first pinned magnetic layer 1131a is pinned in the height direction.

After annealing, the upper shield layer 50 is deposited by sputtering over the exposed second insulating layers 64

5   and upper nonmagnetic metal film 540 to cover the exposed surfaces of the pinned magnetic layer 1131 and the upper nonmagnetic metal film 540.

The CPP-GMR head 1101 shown in Figs. 44 to 46 is completed by the above-described steps.

10   In each of the ninth to eleventh embodiments, magnetization of the pinned magnetic layer 231, 731 or 1131 can be strongly pinned, and the sensing current density can be increased to increase output. Even when the sensing current flows, the antiferromagnetic layer 234 or 734 or the

15   insulating antiferromagnetic layer 1131 does not generate heat to suppress an increase in the element temperature, thereby improving reliability. Furthermore, the shield distance R-GL at the surface facing the recording medium can be narrowed to increase resolution, as compared with the

20   conventional head shown in Fig. 55.

Like in the ninth to eleventh embodiments, in the third to eighth embodiments, the insulating antiferromagnetic layer can be used in place of the antiferromagnetic layer. Like in the fifth to eighth embodiments, when the insulating

25   antiferromagnetic layer is provided on the top of the pinned magnetic layer, a greater exchange coupling magnetic field can be obtained by providing the antiferromagnetic metal layer between the pinned magnetic layer and the insulating

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antiferromagnetic layer. Although the insulating
antiferromagnetic layer is liable to have a higher blocking
temperature than that of the antiferromagnetic metal film,
the use of the insulating antiferromagnetic causes no problem

5   because the insulating antiferromagnetic layer is disposed
outside the GMR element to avoid an excessive increase in
temperature.

Figs. 49 to 51 show a CPP giant magnetoresistive head
(CPP-GMR head) according to a twelfth embodiment of the

10   present invention.

Unlike in the first to eleventh embodiments, in the
twelfth embodiment, the present invention is applied to a
dual spin-valve CPP-GMR head, not a single spin-valve type.

Fig. 49 is a partial sectional view showing the

15   structure of a CPP-GMR head 1201, taken along a central line
of an element, Fig. 50 is a partial sectional view showing
the structure of the CPP-GMR head 1201, as viewed from a
surface facing a recording medium, and Fig. 51 is a schematic
top plan view of a GMR element.

20   The CPP-GMR head 1201 is a dual spin-valve type having a
laminated structure in which the structure of the third
embodiment shown in Figs. 14 to 16 and the structure of the
seventh embodiment shown in Figs. 36 to 38 are laminated. In
Figs. 49 to 51, the functions, shapes, materials and

25   thicknesses of layers denoted by the same reference numerals
as those in the third embodiment shown in Figs. 14 to 16 and
the seventh embodiment shown in Figs. 36 to 38 are the same
as those in the third embodiment and the seventh embodiment.

Since each of the layers of the CPP-GMR head 1201 is described above in the third embodiment shown in Figs. 14 to 16 and the seventh embodiment shown in Figs. 36 to 38, the description thereof is omitted. Although, in this embodiment,

5 the upper nonmagnetic metal film 540 extends to the antiferromagnetic layer 734 and the backfill gap layer 770, the upper nonmagnetic metal film 540 has the same effect.

The CPP-GMR head 1201 can be manufactured by forming the layers ranging from the lower nonmagnetic metal film 220 to

10 the backfill gap layer 770 on the lower shield layer 10 by the same production method as that of the third embodiment, and then forming the layers ranging from the second pinned magnetic layer 731c to the upper shield layer 50 by the same production method as that of the seventh embodiment.

15 In the CPP-GMR head 1201, in order to prevent a sensing current loss, the antiferromagnetic layer 334 in contact with the upper surface of the upper first pinned magnetic layer 731a preferably comprises an insulating antiferromagnetic layer. When the antiferromagnetic layer 334 comprises an

20 insulating antiferromagnetic layer, the antiferromagnetic layer 734 in contact with the lower surface of the lower first pinned magnetic layer 331a can be formed by using an antiferromagnetic metal layer.

Figs. 52 to 54 show a CPP giant magnetoresistive head

25 (CPP-GMR head) according to a thirteenth embodiment of the present invention.

Fig. 52 is a partial sectional view showing the structure of a CPP-GMR head 1301, taken along a central line

of an element, Fig. 53 is a partial sectional view showing

the structure of the CPP-GMR head 1301, as viewed from a

surface facing a recording medium, and Fig. 54 is a schematic

top plan view of a GMR element.

5   The CPP-GMR head 1301 is a dual spin-valve type having a

laminated structure in which the structure of the ninth

embodiment shown in Fig. 42 and the structure of the eleventh

embodiment shown in Figs. 44 to 46 are laminated. In Figs.

52 to 54, the functions, shapes, materials and thicknesses of

10   layers denoted by the same reference numerals as those in

Figs. 42 and 44 to 46 are the same as those in the ninth

embodiment and the eleventh embodiment. Since each of the

layers of the CPP-GMR head 1301 is described above in the

ninth embodiment and the eleventh embodiment, the description

15   thereof is omitted.

The CPP-GMR head 1301 can be manufactured by forming the

layers ranging from the lower nonmagnetic metal film 220 to

the free magnetic layer 233 on the lower shield layer 10 by

the same production method as that of the ninth embodiment,

20   and then forming the layers ranging from the upper

nonmagnetic layer 732 to the upper shield layer 50 by the

same production method as that of the eleventh embodiment.

In the CPP-GMR head 1301, an antiferromagnetic metal

layer in contact with the lower pinned magnetic layer 231 and

25   an insulating antiferromagnetic layer in contact with the

upper pinned magnetic layer 731 can be provided in place of

the antiferromagnetic 234' in contact with the rear portions

of the lower pinned magnetic layer 231 and the upper pinned

magnetic layer 731 in the rear of the free magnetic layer 233

and the nonmagnetic layers 232 and 732 in the height

direction.   In this embodiment, coupling between the

insulating antiferromagnetic layer and the lower pinned

5   magnetic layer can be improved while suppressing a sensing

current loss.

In each of the twelfth and thirteenth embodiments,

magnetization of the pinned magnetic layers 231 and 731 can

be strongly pinned, and the sensing current density can be

10   increased to increase output.   Even when the sensing current

flows, the antiferromagnetic layers 234 and 734 do not

generate heat to suppress an increase in the element

temperature, thereby improving reliability.   Furthermore, the

shield distance R-GL at the surface facing the recording

15   medium can be narrowed to increase resolution, as compared

with the conventional heat shown in Fig. 55.

The CPP-GMR head of each of the above embodiments can be

applied not only to a reproducing thin film magnetic head but

also to a recording thin film magnetic head comprising a

20   recording inductive head laminated on the reproducing thin

film magnetic head.